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EBR-II Project

November 1971

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ABSTRACT

The Mark IIB oscillator rod enables measurement of reactor transfer functions by rotating an absorber material (boron carbide) toward and away from the center of the reactor to perturb reactivity. Its design has eliminated two operating problems encountered with previous EBR-II oscillator rods: bowing and consequent rubbing of the rod in its guide tube, and failure of the seals that prevent air from contacting the sodium coolant. The Mark IIB rod and its drive were installed in EBR-II in April 1971. Both have performed satisfactorily since then.

I. INTRODUCTION

The oscillator rod is a special device designed to sinusoidally perturb the reactivity of the EBR-II reactor by moving an absorber material toward and away from the center of the reactor. This reactivity perturbation, when correlated with the resulting sinusoidal flux perturbation, is used to measure the reactor transfer functions under a variety of reactor conditions.

Oscillator rods have been used in EBR-II for many years. Each has been installed in a control-rod position, replacing the control rod itself. All EBR-II control rods operate in guide tubes (or thimbles) that are hexagonal in cross section and are locked at the bottom to a pin attached to the lower grid plate of the reactor. The initial oscillator rod* used during the dry critical tests was externally similar to a control rod and contained boron carbide as the absorber. It was inserted into a control-rod guide tube (after the control rod was removed) in the reactor. The control-rod drive was used to position the rod, and thus the boron carbide, at predetermined elevations within the core region. The position of the rod was not continuously variable. This rod was used only during the dry critical tests to verify the design criteria previously computed.

*EBR-II System Design Descriptions, Volume II, "Primary System," Chapter 2, Paragraph 2.6.8. These are EBR-II Project documents. Single copies of cited portions are available on request to the EBR-II Project.

The second design, designated the Mark I oscillator rod,* had its own drive assembly and guide tube, and was used during reactor operation. It replaced the No. 8 control rod and control-rod-drive assembly (see Fig. 1). This rod also contained boron carbide and had a vertical reciprocating motion. It was used for only a short time because one of the linear ball bearings on the drive shaft failed. The rod had a maximum operating frequency of 1.7 Hz, which is too low for analysis of the relatively prompt feedback associated with expansion of reactor fuel.

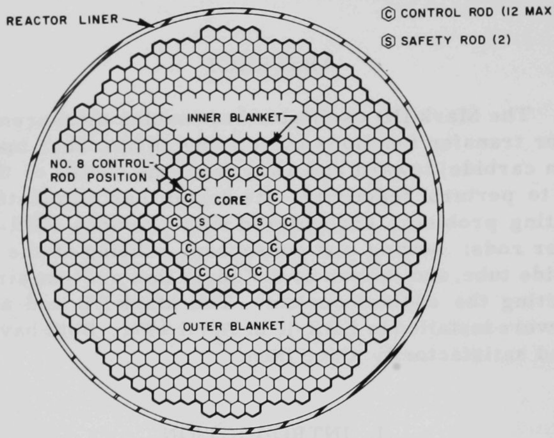

Fig. 1. EBR-II Reactor Grid, Showing Location of Control and Safety Rods

The third design, designated the Mark II oscillator rod, also had its own drive assembly, but used the rotation concept. It replaced the Mark I oscillator rod and drive assembly in the No. 8 control-rod position. The rod contained one capsule of boron carbide pellets and one of aluminum oxide pellets, positioned equally distant from the vertical centerline of the rod and opposite each other. For dynamic balance, the capsules had the same weight. The rod operated inside the standard control-rod guide tube and was capable of rotational speeds of 0.002-10 Hz. When it was operated below 0.3 Hz with the reactor operating above 30 MWt, temperature differentials were sufficient to cause the rod to bow enough to lightly rub against its enclosing guide tube. This rubbing distorted the experimental data.

The fourth design of the oscillator rod, designated the Mark IIA, was essentially the same as the Mark II, but was smaller in diameter to allow more clearance between it and the guide tube. It used the same drive assembly as the Mark II. The new feature of this design was the capability of storing the rod in the storage basket when it was not being used in the

*EBR-II System Design Descriptions, Volume II, "Primary System," Chapter 2, Paragraph 2.9.

reactor. The Mark IIA was never fabricated, because predictions indicated that it would not eliminate the bowing effects experienced with the Mark II design.

The latest design of the oscillator rod is designated Mark IIB. It uses essentially the same drive assembly as the Mark II oscillator rod. Several new hydraulic features are incorporated to minimize the amount of bowing. This concept also provides the capability of storing the oscillator rod in the storage basket.

As in the previous oscillator rods based on the rotational concept, no rotating part of the rod or its drive moves directly against a component of the primary tank or reactor. Thus, no seizure can occur between a rotating part and the primary-tank and reactor components.

The balance of this report is confined principally to the Mark IIB oscillator rod, its drive, and associated components.

II. THE MARK IIB OSCILLATOR ROD

The Mark IIB oscillator rod consists of the Mark IIB oscillator-rod subassembly (Figs. 2 and 3) and the lower-bearing and bayonet-lock subassembly (Fig. 4). Like the previous models of the oscillator rod, the Mark IIB has its own guide tube and does not use the control-rod guide tube. The guide tube is locked to a pin in the lower grid plate of the reactor, and the oscillator rod is locked to a pin in the lower portion of the tube. The rod may be stored in an adapter sleeve in the storage basket when not in use. This extends its useful life. When the rod is removed from the reactor grid and stored in the basket, it is replaced by a nonfueled dummy rod. The rod weighs 17.6 lb in air and 16.1 lb in sodium.

Unless stated otherwise in the following description, all components were made of Type 304 stainless steel.

A. Oscillator-rod Assembly

1. Oscillator-rod Subassembly

The oscillator-rod subassembly (see Figs. 2 and 3) is 59.141 in. long and 1.75 in. in diameter. Its principal components are: (a) a top end fixture, the part gripped during fuel handling; (b) an outer-tube assembly, whose tube forms the outer wall of the rod subassembly; (c) an expansion chamber, which holds the helium gas generated by the neutron transmutation of ^{10}B in the boron carbide; (d) two capsule assemblies, one holding the pellets of boron carbide, and the other the pellets of aluminum oxide; and (e) a fitting, welded to the bottom of the outer tube, which engages an

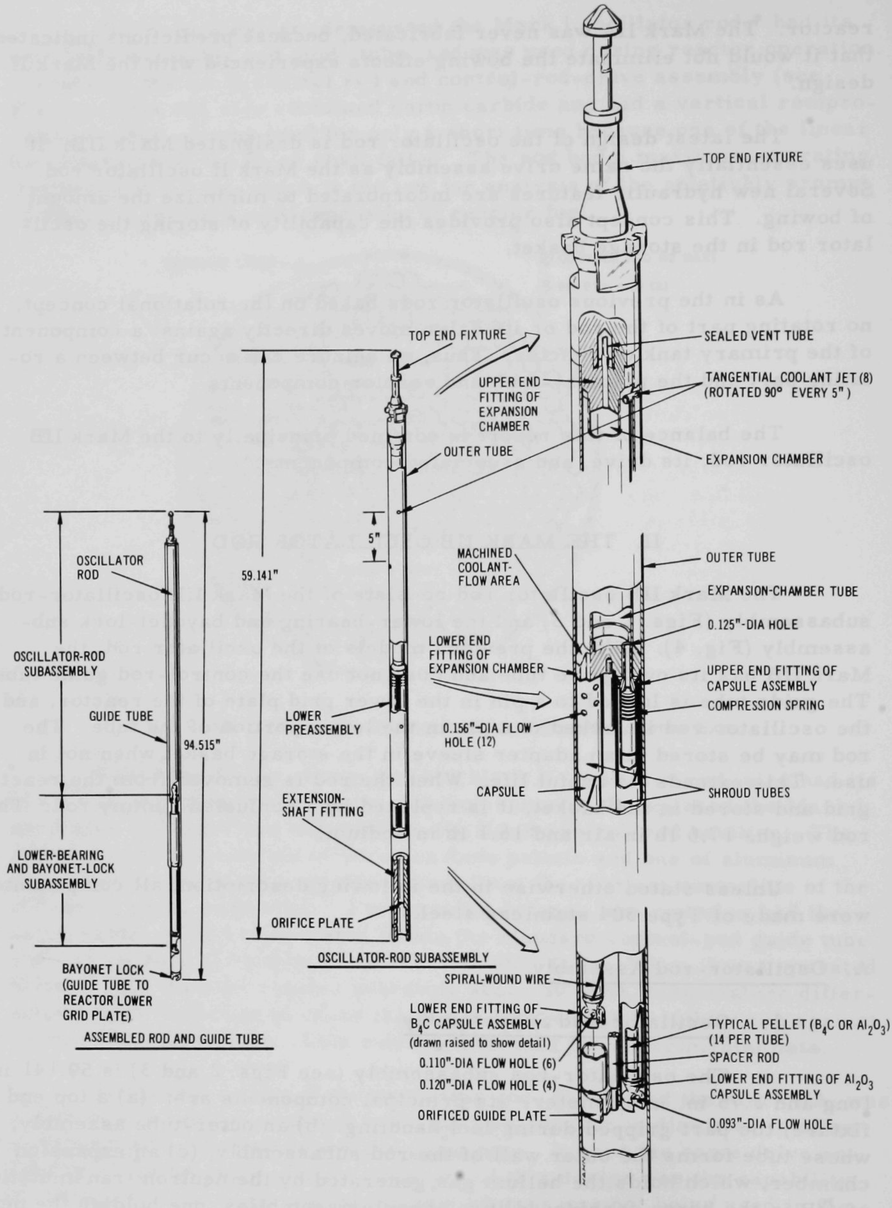

Fig. 2. General Configuration of Mark IIB Oscillator Rod

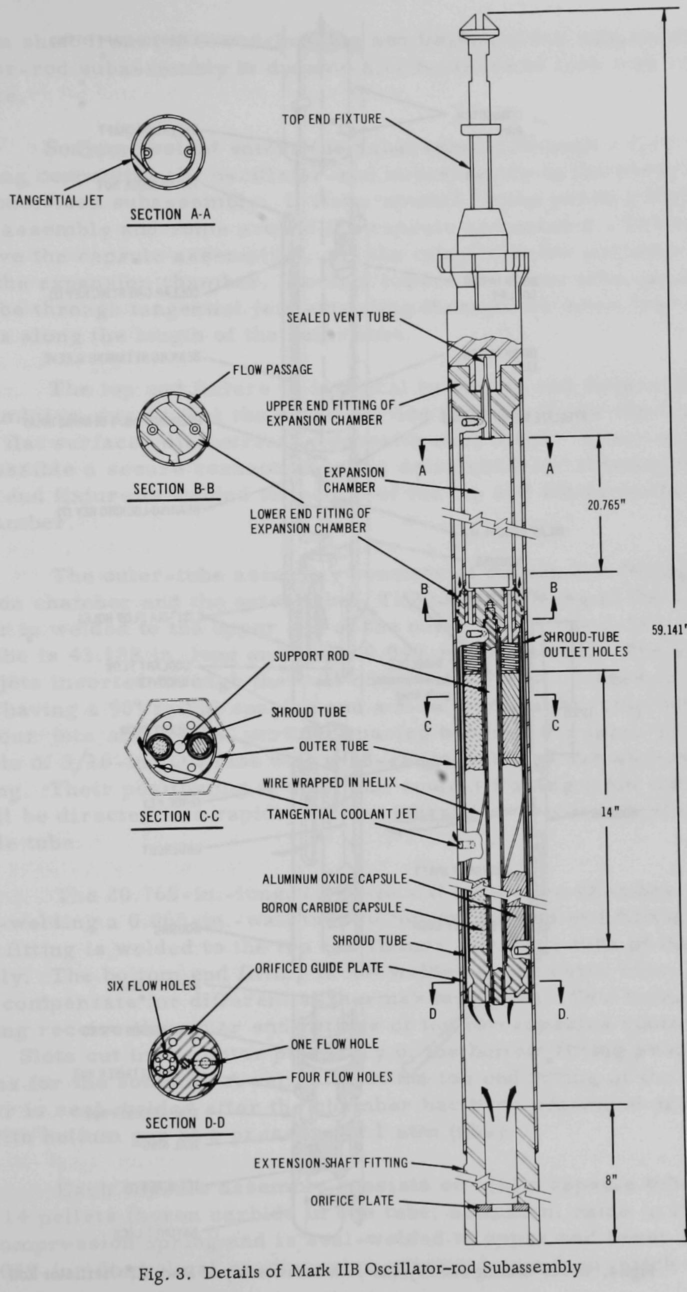

Fig. 3. Details of Mark IIB Oscillator-rod Subassembly

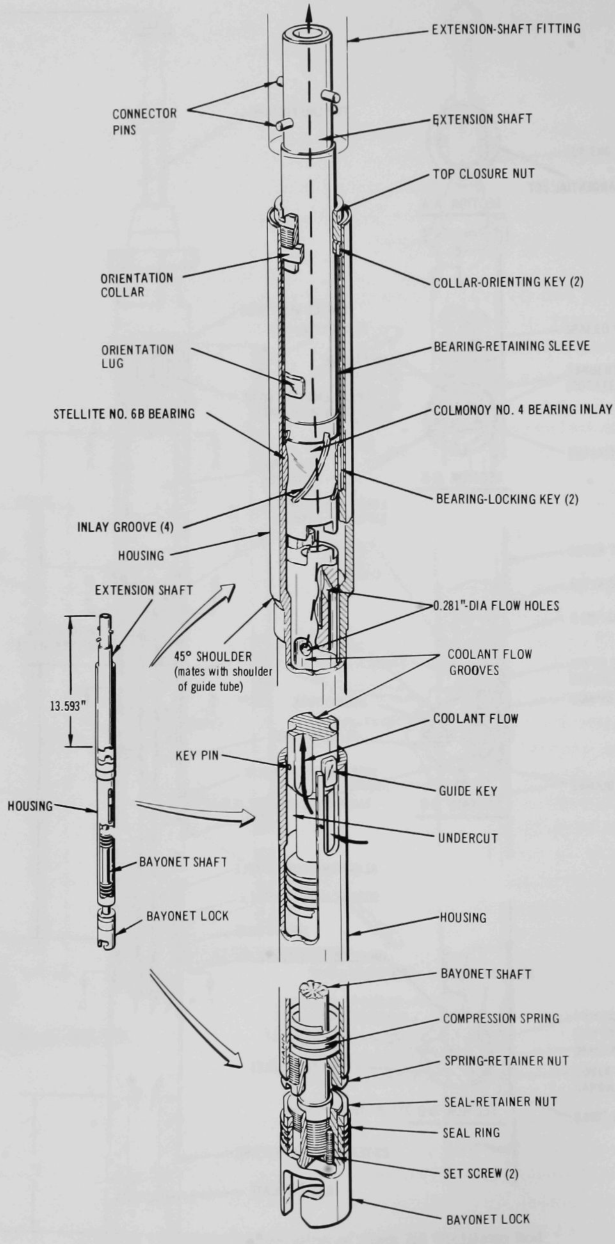

Fig. 4. Lower-bearing and Bayonet-lock Subassembly of Mark IIB Oscillator Rod

extension shaft from the lower-bearing and bayonet-lock subassembly. The oscillator-rod subassembly is dynamically balanced to less than 1 in.-oz of unbalance.

Sodium coolant enters the subassembly through a flow orifice in a fitting connecting the oscillator-rod subassembly to the lower-bearing and bayonet-lock subassembly. It flows upward, some passing through each capsule assembly and some around the capsule assemblies. The two flows join above the capsule assemblies, and the mingled flows continue upward around the expansion chamber. Coolant leaves the outer tube and enters the guide tube through tangential jets extending through the outer tube at eight locations along the length of the outer tube.

The top end fixture is identical to the top end fixture of the fuel subassemblies, except that the round portion directly below the conical tip has two flat surfaces diametrically opposite each other. These surfaces make possible a secure connection to the drive shaft for rotating the rod. The top end fixture is welded to the top of the top end fitting of the expansion chamber.

The outer-tube assembly consists of the top end fitting of the expansion chamber and the outer tube. The top end fitting of the expansion chamber is welded to the upper end of the outer tube. The 1.750-in.-OD outer tube is 43.188 in. long and has a 0.049-in.-thick wall. The eight tangential jets inserted through the wall of the tube are positioned in a helical pattern having a 90° radial spacing and a 5-in. vertical spacing between the lower four jets and $5\frac{5}{8}$-in. vertical spacing between the upper jets. They are made of 3/16-in.-OD tube with a 28-gauge wall and are approximately 1 in. long. Their positioning is such that coolant flowing from the outer tube will be directed in a rapidly mixing spiral flow between that tube and the guide tube.

The 20.765-in.-long, 1.120-in.-ID expansion chamber is formed by seal-welding a 0.065-in.-wall tube to top and bottom end fittings. The top end fitting is welded to the top end fixture and outer tube of the rod subassembly. The bottom end fitting is not welded to the outer tube; it is left free to compensate for differential thermal expansion. Two holes through the fitting receive the upper end fittings of the two capsules containing the pellets. Slots cut in the outer periphery of the bottom fitting provide flow passages for the sodium. A vent tube in the top end fitting of the expansion chamber is seal-welded after the chamber has been evacuated and then filled with helium gas at a pressure of 1 atm (abs).

Each capsule assembly consists of: (a) a capsule tube, which houses 14 pellets (boron carbide in one tube, aluminum oxide in the other) and a compression spring and is seal-welded to upper and lower end fittings; (b) a 0.049-in.-dia helical spacing wire, wrapped on a 6-in. pitch around each tube; and (c) a shroud tube around each capsule tube and its spacing wire. The assemblies are 180° apart. The centerline of each is 0.466 in. from the centerline of the oscillator rod.

Both capsule tubes are 0.500 in. in OD x 0.446 in. in ID x 15.2 in. long. All pellets are 0.440 in. in diameter x 1 in. long. The compression springs are made of Inconel X.

The upper end fittings of both capsules are identical. The top portion of each fits into and is seal-welded in a corresponding hole through the bottom end fitting of the expansion chamber. Gas is vented from the pellets to the expansion chamber through holes bored through the upper end fittings of both capsules.

The lower end fittings of both capsules are hourglass-shaped and fit snugly inside their shroud tubes. There, the similarity ends. The size, configuration, and number of coolant flow holes are different for each. The capsule with the boron carbide requires considerably more flow than the one with the aluminum oxide. Its end fitting has six 0.110-in.-dia flow holes drilled vertically through the bottom end of the fitting to the necked-down portion of the fitting. The coolant flows through these holes and up between the capsule tube and the shroud tube, following the helical path provided by the spacing wire. The lower end fitting of the capsule with the aluminum oxide has one 0.093-in.-dia hole drilled at an angle from the necked-down portion of the fitting to a 0.062-in.-wide, 0.125-in.-deep slot in the bottom surface of the fitting. The slot would prevent any large particles that may be in the coolant from plugging the flow hole. Coolant leaving the hole follows a path similar to that of the coolant for the boron carbide capsule.

The shroud tube of each capsule has a 0.640-in. OD and a 0.027-in. wall thickness. Its top is welded to the upper end fitting of the capsule. The sodium flowing between the shroud tube and the capsule leaves through twelve 0.156-in.-dia holes near the upper end of the tube.

The bottom of the lower end fittings and the shroud tubes of the capsule extend through an orificed guide plate that is supported by a central support rod attached to the lower end fitting of the expansion chamber. The plate is not attached to the outer tube of the oscillator-rod subassembly. Therefore, all internal components of the subassembly below the top end fitting of the expansion chamber are free to expand differentially within the outer tube. In addition to containing the two large holes through which coolant enters the two capsule assemblies, the plate has four 0.120-in.-dia holes through which coolant flows into the area around the assemblies.

All coolant enters the oscillator-rod subassembly through a 0.375-in.-dia orifice in an orifice plate mounted in the bore of the extension-shaft fitting that connects the oscillator-rod subassembly to the lower-bearing and bayonet-lock subassembly. This fitting is welded to the lower end of the oscillator-rod subassembly.

2. Lower-bearing and Bayonet-lock Subassembly

The lower-bearing and bayonet-lock subassembly (Fig. 4), which is locked at its bottom to the lower portion of the guide tube, provides a stable lower bearing for the oscillator rod while it is being rotated. Its main components are: (a) a center-bored extension shaft, which is the mechanical and coolant-flow linkage between the lower-bearing and bayonet-lock subassembly and the oscillator-rod subassembly; (b) a housing, which encloses all components except a bayonet lock at the bottom of the subassembly; (c) the bearing; (d) the bayonet shaft, which maintains proper orientation of the entire oscillator rod and, through a compression spring, stabilizes the bearing; and (e) the bayonet lock, which locks to a pin in the guide tube.

Coolant enters through two 3.5 x 0.252-in. slots in the housing, flows upward through four machined grooves in the outer surface of the bayonet shaft, enters the center-bored upper portion of the shaft through a 0.281-in.-dia hole at the top of each groove, and then flows through the extension shaft into the oscillator-rod subassembly.

The 13.593-in.-long, 1.375-in.-dia extension shaft has a center full-length bore of 0.750 in. The top of the shaft is attached to the extension-shaft fitting by four pins driven into the shaft wall. Near the bottom of the shaft is a Colmonoy No. 4 bearing-surface inlay that is 1.5 in. long and has a nominal OD of 1.5 in.

Four grooves with a 30° helix are equally spaced in the circumference of the inlay. These grooves promote flushing of the bearing with a 7-gpm sodium flow that passes through the bearing area and along the outside of the extension shaft. (This flow does not go through the oscillator-rod subassembly; it goes between that subassembly and the guide tube.) Two notches in the bottom end of the extension shaft engage projections in the top end of the bayonet shaft. Two projections (orientation lugs) on the periphery of the extension shaft, about $4\frac{3}{8}$ in. up from the bottom of the shaft, engage notches in an orientation collar to keep the top end fixture and the bayonet lock properly oriented while the oscillator rod is being handled by the reactor fuel-handling mechanisms.

The housing contains the upper portion of the extension shaft, the orientation collar, the bearing, the bayonet shaft, and the compression spring. The Stellite No. 6B bearing is held in place by a bearing-retaining sleeve and by two keys that engage keyways in the outer surface of the bearing and in the inner surface of the housing of the subassembly. The orientation collar rests on the bearing-retaining sleeve, and both are held in place by a hollow top-closure nut. The collar is oriented by two keys that fit into keyways in the outer surface of the collar and the inner surface of the subassembly housing. The bayonet shaft, located in the lower portion of the bearing housing, is held in proper orientation by a guide key that fits through a hole in the bayonet shaft and engages slots in the subassembly housing. With the guide key in place, the projections on the top end of the bayonet shaft are properly oriented to engage the notches in the bottom end of the extension shaft, and the bayonet lock is also properly oriented to engage the pin of the guide tube. The slots for the guide key are also the coolant-inlet slots of the subassembly. The coolant enters the area around an undercut portion on the bayonet shaft, and then flows upward as described previously.

The Inconel X compression spring is trapped between the shoulder on the bayonet shaft and the spring-retainer nut at the bottom of the subassembly housing. The spring provides rigid support for the bearing by seating the 45° shoulder of the subassembly housing against the shoulder of the guide tube with a force of about 200 lb when the bayonet has been locked into the guide-tube pin.

The bayonet lock is screwed and locked with setscrews onto the bottom end of the bayonet shaft, which extends through the spring-retainer nut. An Ampco 18-13 aluminum-bronze labyrinth seal ring is locked onto the bayonet-lock body by a seal-retainer nut screwed onto the upper end of the bayonet lock.

B. Guide-tube Assembly

The guide-tube assembly (Fig. 5) consists principally of a hexagonal tube, a lower adapter, and a bayonet lock. The hexagonal tube (49.5 in. long) has the same cross section as that of the outer hexagonal tube of standard fuel subassemblies: 2.290 in. across flats and a wall thickness of 0.040 in. One spacing button is on each flat of the tube, as with standard fuel subassemblies. Two holes at the upper end of each flat accommodate special handling tools, if needed.

The lower adapter is made in one piece, but has three sections. The upper section, which extends into the hexagonal tube and is welded to that tube, is hexagonal outside and cylindrical inside. The middle section, which also is cylindrical inside, has an outer profile that matches the outer profile of the hexagonal tube. The lower section is cylindrical outside and inside. This section fits into the reactor grid.

A spherical shoulder at the transition between the middle and lower sections seats on the chamfer around the hole in the top grid plate of the reactor. The seat for the housing of the lower-bearing and bayonet-lock subassembly of the oscillator rod is about 0.6 in. above this spherical shoulder, inside the lower portion of the middle section of the adapter. The

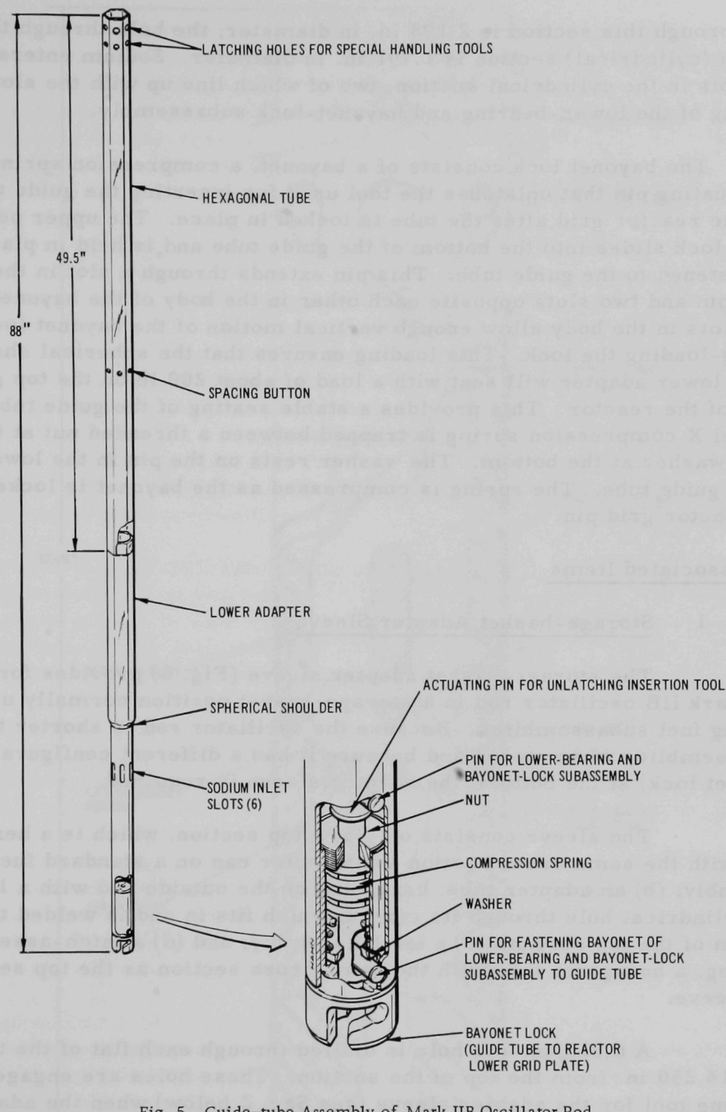

Fig. 5. Guide-tube Assembly of Mark IIB Oscillator Rod

hole through this section is 2.198 in. in diameter; the hole through the bottom (cylindrical) section is 1.791 in. in diameter. Sodium enters through six slots in the cylindrical section, two of which line up with the slots in the housing of the lower-bearing and bayonet-lock subassembly.

The bayonet lock consists of a bayonet, a compression spring, and an actuating pin that unlatches the tool used for inserting the guide tube into the reactor grid after the tube is locked in place. The upper portion of the lock slides into the bottom of the guide tube and is held in place by a pin fastened to the guide tube. This pin extends through a slot in the actuating pin and two slots opposite each other in the body of the bayonet lock. The slots in the body allow enough vertical motion of the bayonet lock for spring-loading the lock. This loading ensures that the spherical shoulder of the lower adapter will seat with a load of about 200 lb on the top grid plate of the reactor. This provides a stable seating of the guide tube. The Inconel X compression spring is trapped between a threaded nut at the top and a washer at the bottom. The washer rests on the pin in the lower end of the guide tube. The spring is compressed as the bayonet is locked to the reactor grid pin.

C. Associated Items

1. Storage-basket Adapter Sleeve

The storage-basket adapter sleeve (Fig. 6) provides for storing the Mark IIB oscillator rod in a storage-basket position normally used for storing fuel subassemblies. Because the oscillator rod is shorter than those subassemblies when stored and because it has a different configuration (the bayonet lock) at the bottom, the adapter sleeve is required.

The sleeve consists of: (a) a top section, which is a hexagonal tube with the same cross section as the outer can on a standard fuel subassembly; (b) an adapter tube, hexagonal on the outside and with a 1.803-in.-dia cylindrical hole through its center, which fits in and is welded to the bottom of the top section; (c) a latch assembly; and (d) a latch-assembly housing, a hexagonal tube with the same cross section as the top section of the sleeve.

A 0.515-in.-dia hole is drilled through each flat of the top section, 14.250 in. from the top of the section. These holes are engaged by the handling tool for the adapter sleeve (see Sec. 2 below) when the adapter sleeve is installed or removed from the storage basket.

The adapter tube contains the lower portion (the lower-bearing and bayonet-lock subassembly) of the stored oscillator rod. An orientation key extending through the walls of the lower portion of the tube engages the bayonet of the rod, holding the rod in proper orientation for fuel-handling mechanisms.

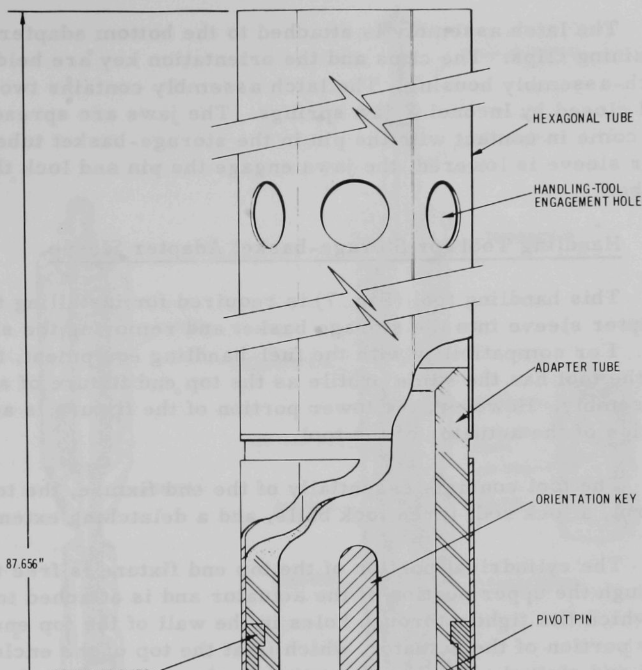

Fig. 6. Storage-basket Adapter Sleeve for Mark IIB Oscillator Rod

The latch assembly is attached to the bottom adapter of the tube by six retaining clips. The clips and the orientation key are held in place by the latch-assembly housing. The latch assembly contains two jaws, normally held closed by Inconel X jaw springs. The jaws are spread apart when they come in contact with the pin in the storage-basket tube, and as the adapter sleeve is lowered, the jaws engage the pin and lock the sleeve into the tube.

2. Handling Tool for Storage-basket Adapter Sleeve

This handling tool (Fig. 7) is required for installing the storage-basket adapter sleeve into the storage basket and removing the sleeve from the basket. For compatibility with the fuel-handling equipment, the top end fixture of the tool has the same profile as the top end fixture of a standard fuel subassembly. However, the lower portion of the fixture is actually the upper portion of the actuator of the tool.

The tool consists essentially of the end fixture, the top actuator, a cam barrel, a lock rod, three lock balls, and a delatching extension.

The cylindrical portion of the top end fixture is free to slide in a hole through the upper portion of the actuator and is attached to the actuator key, which fits tightly through holes in the wall of the top enclosure. The center portion of the actuator, which is at the top of the enclosure, is cylindrical and slotted. The lower portion is also cylindrical, but has a smaller diameter. The upper portion is free to slide within the top enclosure and, because of the slots, over the actuator key. The lower portion, with the actuator spring around it, fits into a blind hole in the center of the cam barrel. The spring holds the actuator in its up position. To minimize friction, thrust washers are at the top and bottom of the spring.

The cam barrel has a cam track in its outer periphery. The track has three lands. The first has the lowest elevation, the second is 3/8 in. higher than the first, and the third is $1\frac{1}{16}$ in. higher than the second. Two cam pins attached to the wall of the top closure engage the cam track in the cam barrel.

The lock rod extends through the gripper body and is spring-loaded from the bottom so that it maintains an upward force on the cam barrel. The spring is at the lower end of the gripper body and is trapped between a spring collar and a spacer held by an end cap. The spring collar is attached to the lock rod with a pin that rides in grooves in the gripper body.

Each of three holes in the gripper body contains one of the lock balls. The holes are counterbored so that the ball will protrude outside the gripper body but will not fall out of the body. Each ball rides in a vertical

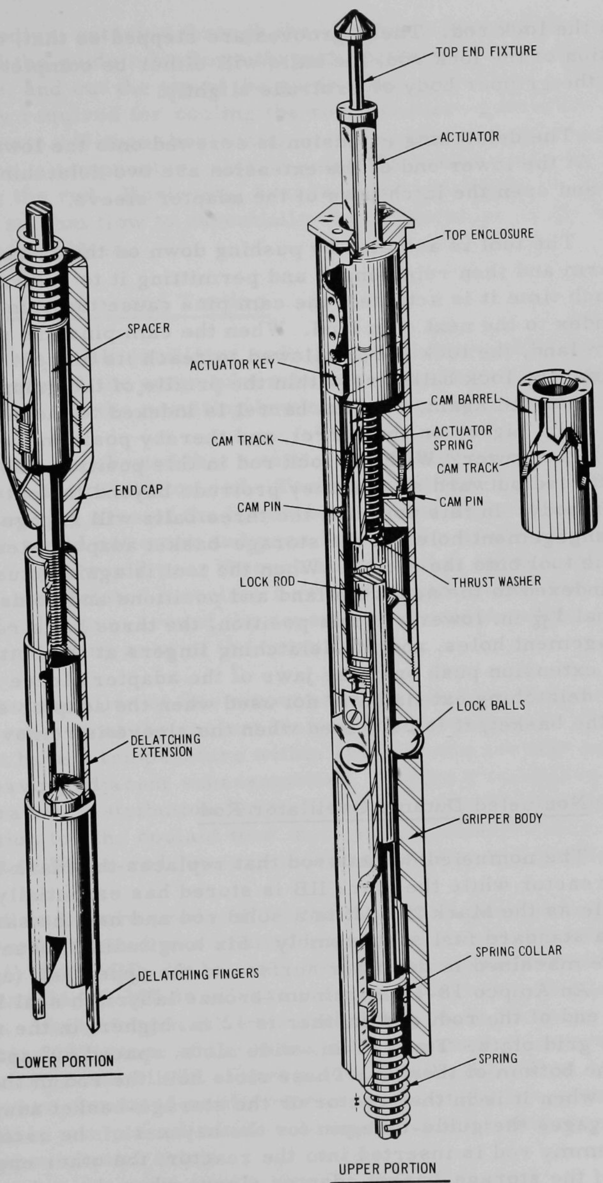

Fig. 7. Handling Tool for Storage-basket Adapter Sleeve

groove on the lock rod. These grooves are stepped so that, depending on the elevation of the lock rod, the balls will either be completely within the profile of the gripper body or protrude slightly.

The delatching extension is screwed onto the lower end of the lock rod. At the lower end of the extension are two delatching fingers used to engage and open the latch jaws of the adapter sleeve.

The tool is actuated by pushing down on the actuator with the transfer arm and then releasing it and permitting it to return to its up position. Each time it is actuated, the cam pins cause the cam barrel to rotate and index to the next cam land. When the cam pins are seated in the lowest cam land, the lock rod is allowed to reach its highest position. In this position, the lock balls are within the profile of the gripper body. When the tool is actuated again, the cam barrel is indexed to the next cam land, which is 3/8 in. higher on the barrel, and thereby positions and holds the lock rod 3/8 in. lower. With the lock rod in this position, the three lock balls are forced outward so that they protrude beyond the outer profile of the gripper body. In this position, the three balls will engage the three matching engagement holes in the storage-basket adapter sleeve (Fig. 6) and lock the tool onto the sleeve. When the tool is again actuated, the cam barrel is indexed to the next cam land and positions and holds the lock rod an additional $1\frac{1}{16}$ in. lower. In this position, the three balls remain locked in the engagement holes, and the delatching fingers at the bottom end of the delatching extension push open the jaws of the adapter sleeve and hold them open. The delatching extension is not used when the adapter sleeve is installed in the basket; it is only used when the sleeve is removed from the basket.

3. Nonfueled Dummy Oscillator Rod

The nonfueled dummy rod that replaces the Mark IIB oscillator rod in the reactor while the Mark IIB is stored has essentially the same outer profile as the Mark IIB. It is a solid rod and has the same top end fixture as a standard fuel subassembly. Six longitudinal, equally spaced grooves are machined in the outer surface of the upper half (approximately) of the rod. An Ampco 18-13 aluminum-bronze labyrinth seal is just above the bottom end of the rod, and another is 12 in. higher, in the region of the reactor top grid plate. Two 1/2-in.-wide slots, spaced 60° apart, are machined in the bottom of the rod. These slots hold the rod in the proper orientation when it is in the reactor or the storage-basket adapter sleeve. One slot engages the guide-tube pin for the bayonet of the oscillator rod when the dummy rod is inserted into the reactor; the other engages the guide key of the storage-basket adapter sleeve when the rod is inserted into the sleeve.

Sodium entering through the clearance between the upper labyrinth seal and the guide tube flows through the annulus between the rod and the guide tube, and out the top of the guide tube. This flow, about 4.5 gpm, is not actually required for cooling the rod, because convection cooling appears adequate. Without horizontal heat transfer from the adjacent core subassemblies, a temperature rise of only 29°F would occur in the sodium passing along the rod. Horizontal heat transfer will raise the temperature of this small sodium flow to essentially the temperature of the flow in adjacent subassemblies.

D. Hydraulic Features and Testing

In the Mark IIB oscillator rod, the spiral flows around the individual capsules and around the outer tube minimize the circumferential temperature differences and the resulting bowing observed with earlier models.

Calculations showed that a total sodium flow rate of 24 gpm would be required for the oscillator rod. Tests showed that 7 gpm would bypass through the bearing area of the lower-bearing and bayonet-lock subassembly and therefore would not enter and pass through the oscillator-rod subassembly. Thus, 17 gpm would pass through and cool that subassembly. Heat-generation rates dictated a coolant flow of 8.5 gpm around the capsule of boron carbide, 1.3 gpm around the capsule of aluminum oxide, and 7.2 gpm through the remaining area of the outer tube.

The combination of this amount and distribution of flow satisfies the basic requirement that the coolant leaving any subassembly in the core of EBR-II must have a temperature within 100°F of the average temperature of coolant leaving adjacent subassemblies. Figure 8 compares the calculated temperature distribution for the two oscillator-rod coolant flows with the distribution for the coolant flow in adjacent subassemblies. The locations of the oscillator-rod jets are included as reference points.

The flow pattern produced by the tangential jets through which coolant leaves the oscillator rod was studied visually in an experimental setup consisting of a 1.75-in.-OD, 20-in.-long cylindrical brass tube assembled concentrically inside a 2.207-in.-ID (across the flats) hexagonal Lucite tube of equal length. Three tangential jets, each 0.116 in. in ID, were mounted around the circumference of the brass tube at elevation increments of 5 in. and radial increments of 90°. Short pieces of silk thread, to serve as flow indicators, were cemented on the outer surface of the brass tube. The whole assembly was placed inside a hexagonal Lucite enclosure. Figure 9 shows the experimental setup.

When water flow rates simulated the operating conditions, the thread flow indicators were 45° above horizontal (see Fig. 10). This indicated that a rapidly mixing, spiral flow was taking place in annular space that simulated the space between the oscillator rod and its guide tube. These tests indicate that the desired mixing, which was predicted to relieve rod bowing, was obtained.

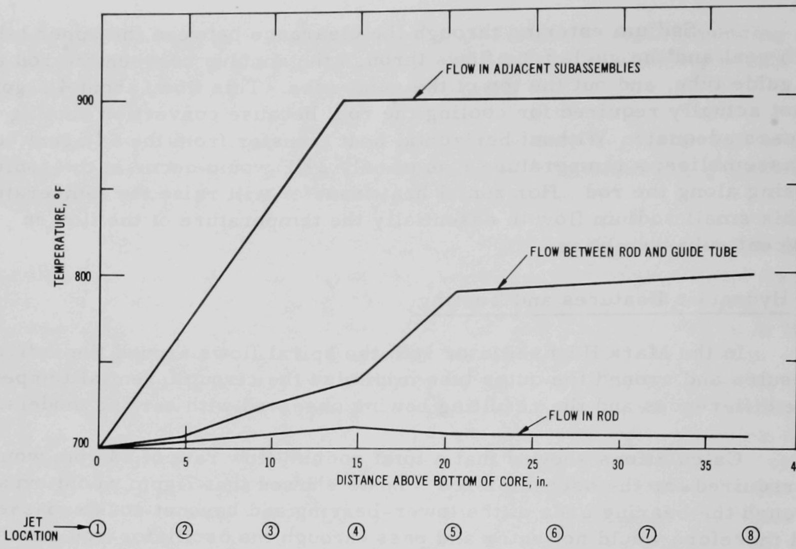

Fig. 8. Calculated Temperature Distribution of Coolant Flows in Mark IIB Oscillator Rod and Adjacent Subassemblies

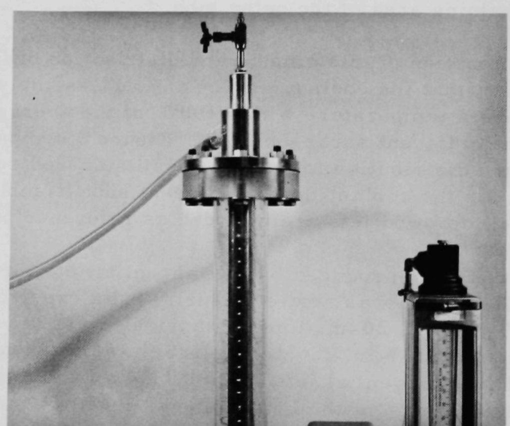

Fig. 9. Setup for Testing Flow Pattern Produced by Tangential Jets of Oscillator Rod. ANL Neg. No. 112-9348 Rev. 1.

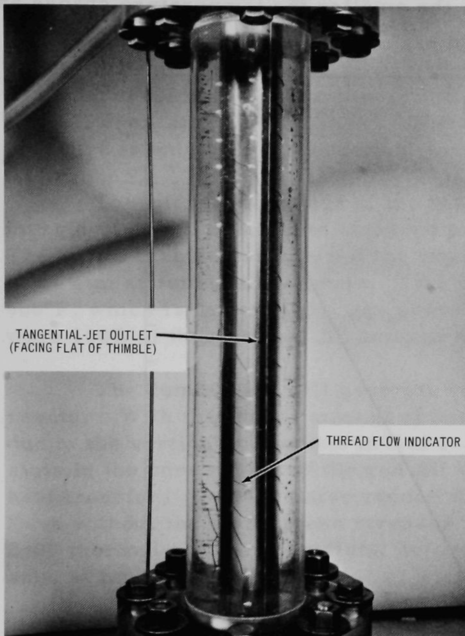

Fig. 10. Closeup Showing Flow Pattern Produced by Jets. ANL Neg. No. 112-9350 Rev. 1.

Flow tests of the capsule assemblies and of all orificing were also made. Finally, the completed oscillator rod was flow tested. The test fluid was pressurized water at 164°F; the data, as indicated by the digital readout instruments, were converted to values for sodium flow at 800°F by correcting for density and viscosity. Figure 11 shows the "Effective Pressure Drop" indicated in the figure is the pressure drop between the lower and upper reactor plenums at the location of the oscillator rod. The figure shows that the desired flow of 24 gpm is achieved at this pressure drop.

E. Analysis of Thermal Stresses

The heat generation in the boron carbide is very small. Most of the heat rise in the sodium flowing up the guide tube results from heat transfer from adjacent subassemblies. The total coolant flow of 24 gpm was calculated to produce a temperature rise of about 100°F less than the average rise in adjacent subassemblies. This temperature difference will lead to stressing of the top end fixtures of the oscillator rod and adjacent subassemblies, as well as nearby reactor-cover components such as thermal shields, holddown fingers, and thermocouples. Before the coolant flows from the oscillator rod and the adjacent subassemblies become thoroughly mixed, the fixtures and components, or portions of them, will be exposed to flow streams whose temperatures may irregularly cycle as much as 100°F. Therefore, the surface temperature of a member may suddenly rise or fall appreciably while the average temperature of the member remains relatively constant. A 100°F difference between the surface temperature and the average temperature will cause surface stresses approaching twice the yield stress at operating temperature. These stresses are within the elastic range; therefore, an almost infinite number of cycles would be required before fatigue failure occurs.

Because of the small temperature rise in the oscillator rod, the thermal stresses due to transient thermal conditions are acceptably small.

A scram subjects the material to rapid cooling. Obviously, the smaller the temperature rise during operation, the smaller the temperature change and the stresses will be upon scram.

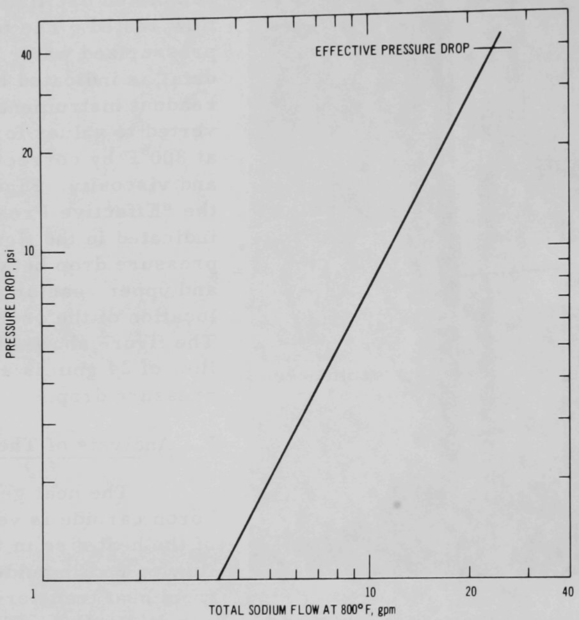

Fig. 11. Relationship between Flow and Pressure Drop in the Mark IIB Oscillator Rod

Calculations and tests have shown that the stresses produced by the gas generated by burnup of the ^{10}B are well within the requirements of the ASME Code.* That Code shows that an allowable stress of 14,000 psi for Type 304 stainless steel at 900°F is permissible if some deformation is acceptable (and some is acceptable in the capsule of boron carbide and the expansion chamber). For conservatism, the design of the capsule and expansion chamber was based on a Code-allowable stress of 9400 psi, which will not cause deformation. A pressure of 69 atm in the capsule and chamber would be required to produce this amount of stress.

The capsule contains 76.4 g of boron carbide, of which 49.5 g is ^{10}B. To achieve the pressure of 69 atm, 4.1 g of ^{10}B would have to be completely burned up and the amount of gas release would have to be 100% of theoretical.

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*ASME Boiler and Pressure Vessel Code, Case Interpretations, 1967, Case 1331-4, "Nuclear Vessels in High Temperature Service," pp. 473-476, The American Society of Mechanical Engineers, New York.

This amount of ^{10}B (4.1 g) is 8.3% of the total amount of ^{10}B in the capsule. The design is based on a burnup of only ~2% (with 100% gas release), much lower than the 8.3% used to calculate the stress. Indications are that release of gas with burnup of the ^{10}B is actually less than 100% of theoretical. After a burnup of 1.8%, the gas pressure in the boron carbide capsule in the earlier Mark II oscillator rod was 7 psi. The amount of gas that would produce this pressure is only 11% of theoretical.

Therefore, the design of the Mark IIB oscillator rod provides a large margin of safety relative to stresses produced by release of fission gas. The boron carbide capsule and the expansion chamber were tested together at 27 atm at room temperature. This pressure is equivalent to 17 atm at 900°F, which is the expected gas pressure at a burnup of 2% if gas release were 100% of theoretical. No leakage or deformation was observed.

The dummy rod will generate very little heat (about 5 kW) in the reactor. With this small amount of heat, the vertical temperature gradient due to the vertical variations in flux is expected to be very small. Vertical slots in the core region of the rod fill with sodium and provide paths of high heat transfer. The slots also reduce the thermal stresses during transients. Even without the slots, these stresses would be acceptable to a limit of about 2500 thermal cycles. The slots, however, provide additional safety assurance at minimal expense.

III. DRIVE SYSTEM

The drive system grips and rotates the oscillator rod at controlled speeds for measurements of reactor transfer function. Except for a slightly modified drive-shaft assembly (see Sec. III.D.7), the drive system for the Mark IIB oscillator rod is essentially the same as that for the Mark II rod.

A. Design Requirements

The basic design requirements set forth for the drive system of the oscillator rod were:

1. Package the drive system so it can be mounted in the No. 8 control-rod position, within the limited area between the adjacent control-rod-drive mechanisms.

2. Incorporate compatibility with the fuel-handling system and procedures.

3. Provide the capability of rotating the oscillator rod through a speed range of 0.06-600 rpm.

4. Include appropriate seals for all shafts penetrating the primary-tank cover, to prevent leakage of the primary-tank blanket gas without restricting linear or rotary motion of the shafts.

5. Ensure that materials used for all components operating in the primary tank are compatible with sodium at 900°F.

6. Provide appropriate electrical and mechanical interlocks to ensure safe operation.

7. Provide the signals necessary for measuring the reactor transfer function.

All these requirements were satisfied or exceeded.

B. General Description

The drive system replaces the control-rod drive at the No. 8 control-rod position. Figure 12 shows a typical EBR-II control-rod drive.

Figure 13 shows the drive system. The major components of the system are: (a) a drive mechanism, which supplies the torque for rotating the rod; (b) a drive-shaft assembly, which transmits the torque to the oscillator rod through a gripper on the lower end of the drive shaft; (c) a gripper-actuating mechanism, which opens and closes the jaws of the gripper; and (d) a position-monitoring assembly, which provides information on position and speed of the oscillator rod to a remote location for use in measuring the transfer function.

The drive system is mounted to brackets attached to the control-rod support column. This column is attached to the control-rod-drive lifting platform, which is supported on top of the small rotating plug at the top center of the reactor primary tank. The drive-shaft assembly extends through the control-rod guide sleeve in the plug.

C. Drive Mechanism

The drive mechanism (Fig. 14) consists of a variable-speed drive, two gearboxes, and a drive-gear assembly. The drive and the gearboxes are attached to the control-rod support column by a common supporting arrangement. The Graham variable-speed drive consists of a $1\frac{1}{2}$-hp motor, a variable-speed transmission, and a Shaftrol remotely controlled, electric, speed-changing motor. The speed of the output shaft of the variable-speed transmission is adjustable from 25 to 600 rpm. The output shaft is coupled through a Morse flexible-chain coupling to the top gearbox. This gearbox contains four shafts. The center shaft is driven (through the Morse coupling) by the output shaft of the variable-speed transmission; the other three shafts operate through a set of gears from that shaft. All four gear shafts turn continuously when the transmission is operating. Under the gearbox, an electric clutch is coupled to the bottom of each shaft. When one of the clutches is engaged, the respective shaft is coupled to a matching shaft in the bottom gearbox. Only one clutch can be engaged at a time. The bottom

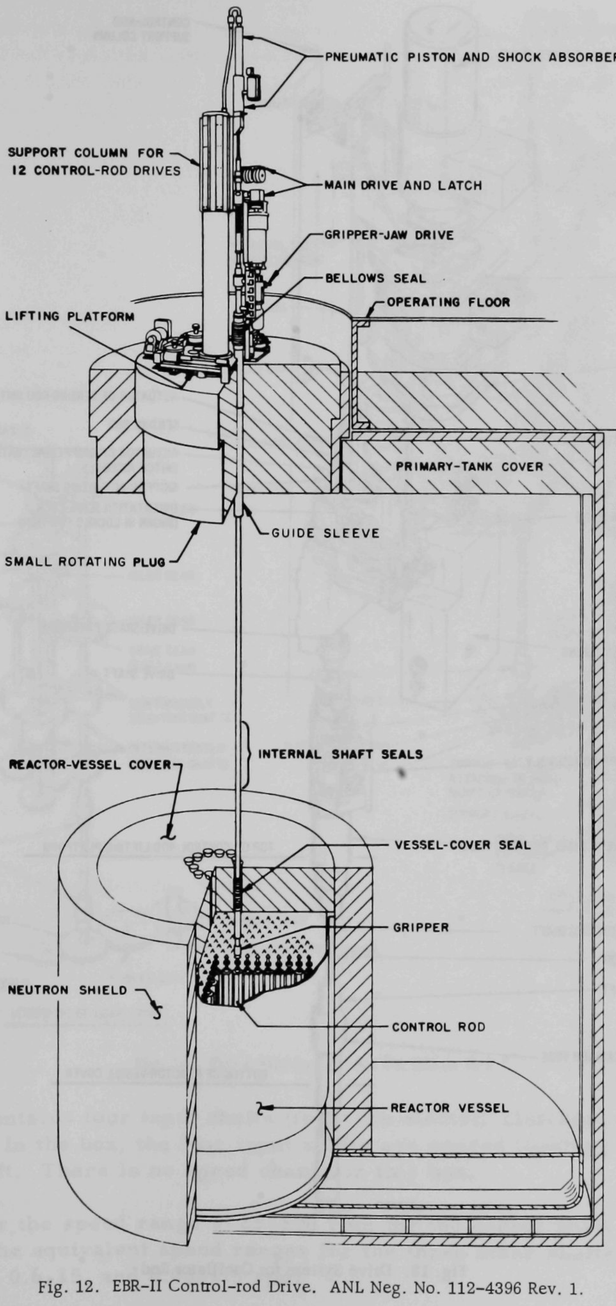


Fig. 12. EBR-II Control-rod Drive. ANL Neg. No. 112-4396 Rev. 1.

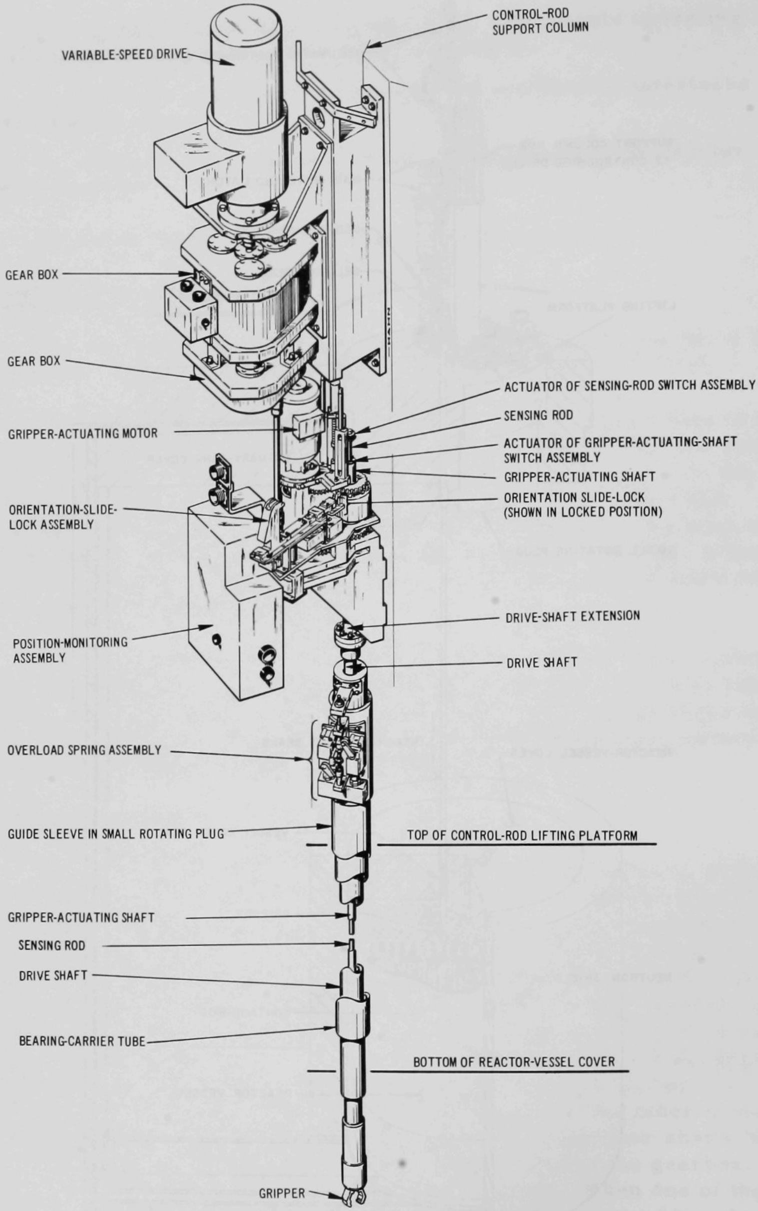


Fig. 13. Drive System for Oscillator Rod

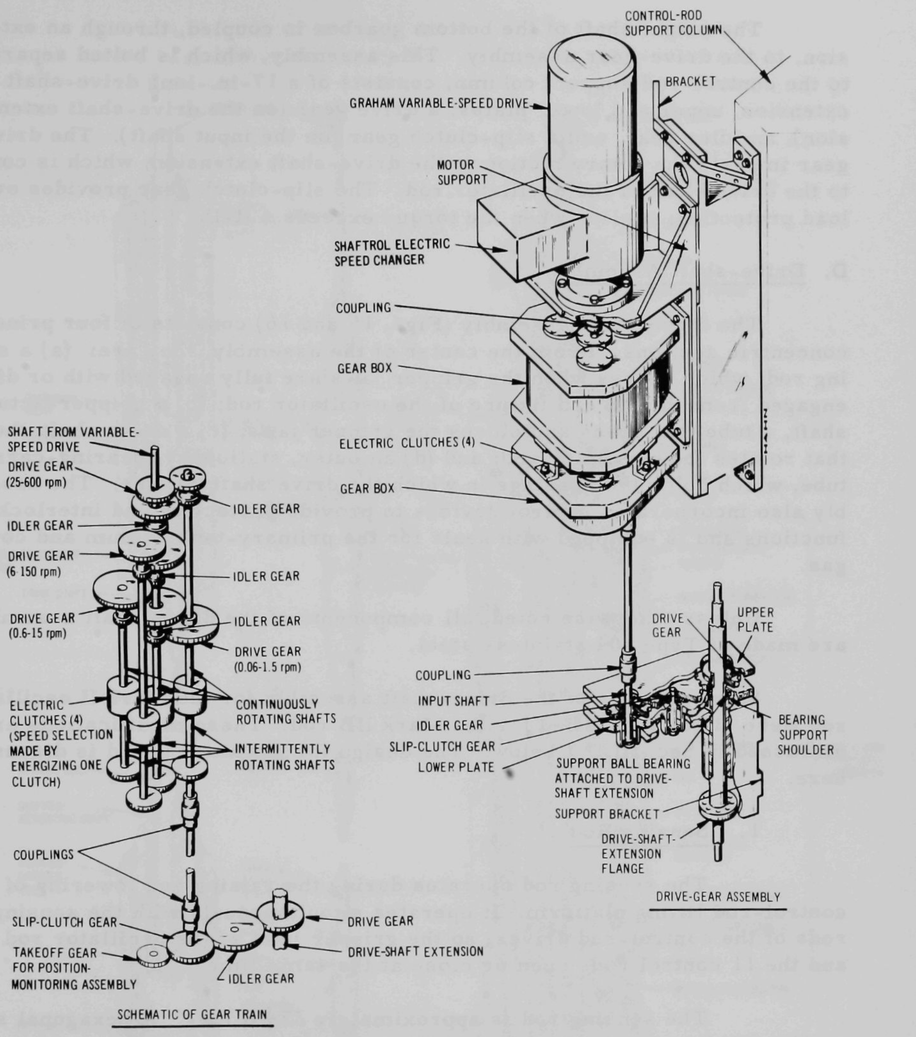


Fig. 14. Drive Mechanism for Oscillator Rod

gearbox contains four input shafts (from the electric clutches) and one output shaft. In the box, the four input shafts are geared together to the one output shaft. There is no speed change in this box.

For the speed range of 25-600 rpm for the center shaft in the top gearbox, the equivalent speed ranges for the three other shafts in the box are 6-150, 0.6-15, and 0.06-1.5 rpm.

The output shaft of the bottom gearbox is coupled, through an extension, to the drive-gear assembly. This assembly, which is bolted separately to the control-rod support column, consists of a 17-in.-long drive-shaft extension, upper and lower plates, a drive gear (on the drive-shaft extension), an idler gear, and a slip-clutch gear (on the input shaft). The drive gear imparts the rotary motion to the drive-shaft extension, which is coupled to the drive shaft of the oscillator rod. The slip-clutch gear provides overload protection; it slips when the torque exceeds 4 ft-lb.

D. Drive-shaft Assembly

The drive-shaft assembly (Figs. 15 and 16) consists of four principal concentric sections. From the center of the assembly, they are: (a) a sensing rod, which senses when the gripper jaws are fully engaged with or disengaged from the top end fixture of the oscillator rod; (b) a gripper-actuating shaft, a tube that opens and closes the gripper jaws; (c) a drive shaft, the tube that rotates the oscillator rod; and (d) an outer, stationary, bearing-carrier tube, which holds the bearings in which the drive shaft rotates. The assembly also incorporates control devices to provide protective and interlocking functions and is equipped with seals for the primary-tank sodium and cover gas.

Unless otherwise noted, all components of the drive-shaft assembly are made of Type 304 stainless steel.

Some portions of the drive-shaft assembly for the Mark II oscillator rod were slightly modified for the Mark IIB rod. These modifications are discussed in Sec. III.D.7 below. The design for the Mark II rod is discussed here.

1. Sensing Rod

The sensing rod operates during the raising and lowering of the control-rod lifting platform. It operates simultaneously with the sensing rods of the control-rod drives, so the gripper jaws of the oscillator rod and the 11 control rods open or close at the same time.

The sensing rod is approximately $27\frac{3}{4}$ ft long. A hexagonal short section on the upper end of the rod fits into a short section of a matching hexagonal interior of the gripper-actuating shaft. (These sections do not appear in Figs. 15 or 16.) This mating fit prevents relative rotary motion between the sensing rod and the gripper-actuating shaft. A sensing tip, with a slot through it to clear the pivot pin of the gripper jaws, is screwed into the lower end of the sensing rod. The end of the tip has a conical recess that mates with the conical tip of the top end fixture of the oscillator rod.

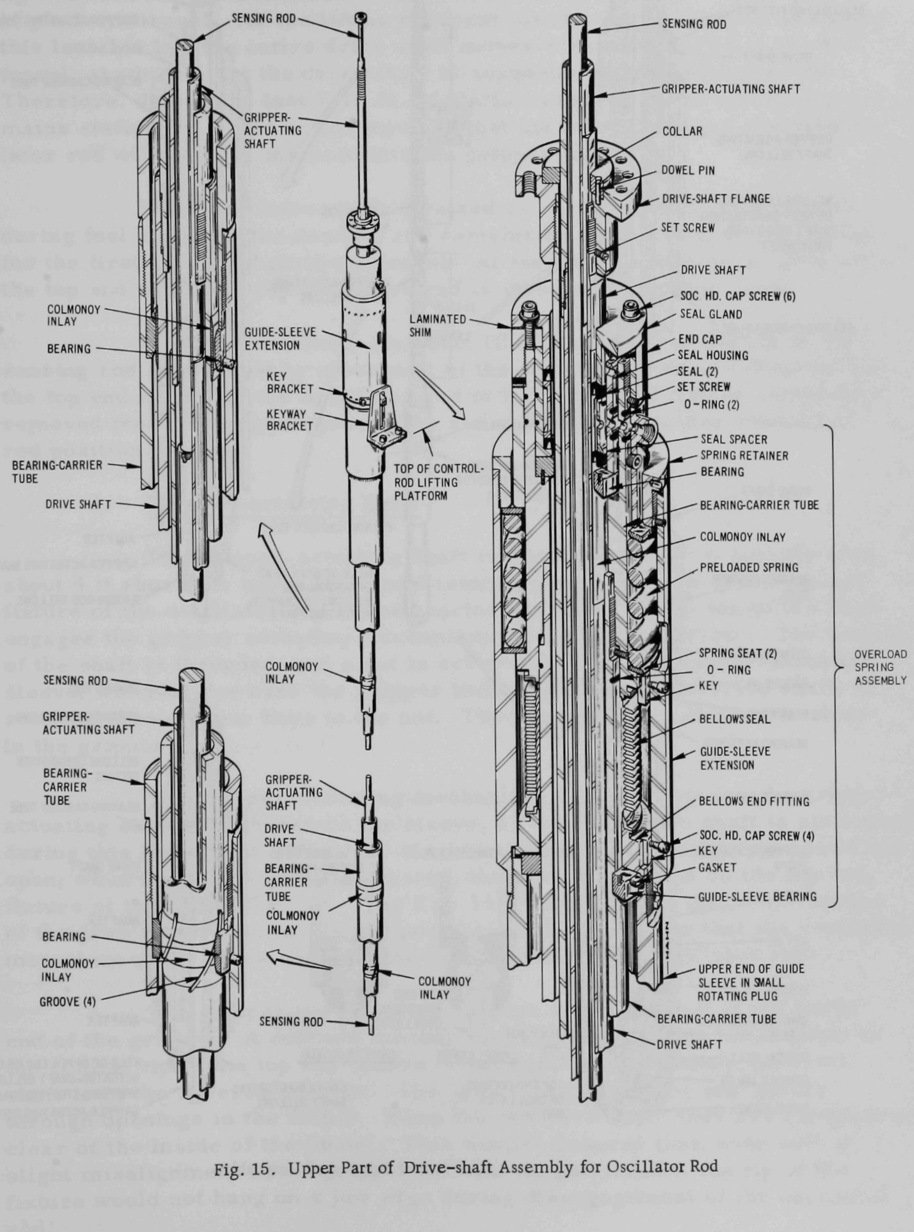


Fig. 15. Upper Part of Drive-shaft Assembly for Oscillator Rod

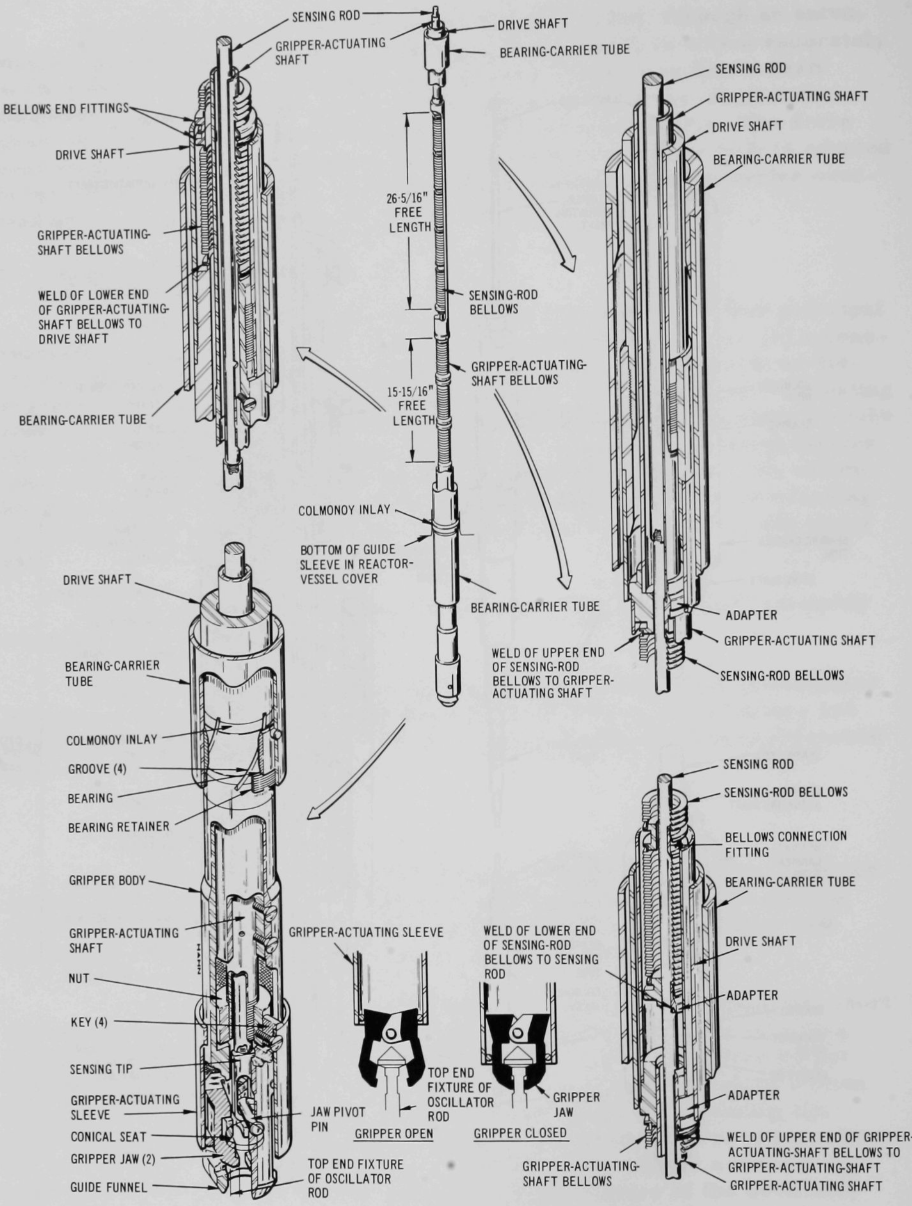


Fig. 16. Lower Part of Drive-shaft Assembly

When the drive-shaft assembly is lowered by lowering the control-rod lifting platform during fuel handling, the bottom of the sensing tip rests on the top end fixture of the oscillator rod during the last 3/4 in. of platform travel. As the lifting platform lowers the drive-shaft assembly this last 3/4 in., the entire drive shaft moves with it for 11/16 in. of the travel, at which point the drive shaft is supported by the oscillator rod. Therefore, during the last 1/16 in. of platform travel, the drive shaft remains stationary. This action ensures that the top end fixture of the oscillator rod will be fully inserted into the gripper jaws.

When the drive shaft is raised by raising the lifting platform during fuel handling, the sensing rod remains in contact with the top adapter for the first 3/4 in. of platform travel. At the end of this amount of travel, the top end fixture of the oscillator rod is clear of the gripper jaws.

A switch assembly (see Sec. III.D.5.a below) at the top of the sensing rod is actuated by movement of the rod and provides indication that the top end fixture of the oscillator rod is fully inserted into or completely removed from the gripper jaws. The assembly also provides readout of rod position.

2. Gripper-actuating Shaft

The gripper-actuating shaft is about 27 ft long; it extends from about 4 ft above the top of the small rotating plug to the top of the top end fixture of the oscillator rod in the reactor vessel. The top end of the shaft engages the gripper actuating mechanism (see Sec. III.E below). The bottom of the shaft is threaded, and a nut is screwed onto it. A gripper-actuating sleeve, which slides over the gripper body at the end of the drive shaft, is screwed through four keys to the nut. The keys ride up and down in slots in the gripper body.

The gripper-actuating mechanism raises or lowers the gripper-actuating shaft, and therefore the sleeve, $1\frac{1}{2}$ in. The drive shaft is stationary during this movement. When the sleeve is fully raised, the gripper jaws are open; when the sleeve is fully lowered, the jaws are closed on the top end fixture of the oscillator rod. (See Fig. 16.) In the closed position, the tips of the jaws are locked on the flat portions of the fixture so that the rotational movement of the drive shaft can be transmitted to the oscillator rod.

The gripper jaws operate through a guide funnel at the lower end of the gripper. A concave conical seat at the top of the funnel rests on the conical tip of the top end fixture of the oscillator rod when the drive shaft is in the lowered position. The jaws close on the top end fixture through openings in the funnel. When the jaws are open, they are completely clear of the inside of the funnel. This feature ensures that, even with a slight misalignment of the gripper and the top end fixture, the tip of the fixture would not hang on a jaw edge during disengagement of the oscillator

A switch assembly (see Sec. III.D.5.b below) at the top of the gripper-actuating shaft is actuated by the shaft and provides indication that the gripper jaws are fully open or fully closed. The assembly also provides readout of shaft position.

The gripper jaws are made of Type 410 stainless steel and are hard-chrome-plated. The jaw pivot pin is made of Rex AA tool steel and is also hard-chrome-plated. The lower portion of the gripper-actuating sleeve, which contacts the gripper jaws, is made of Stellite No. 6B.

3. Drive Shaft

The drive shaft, about $25\frac{3}{4}$ ft long, is fastened to the drive-shaft extension by a bolted flange connection at the upper end of the drive shaft. Relative rotary motion between the drive shaft and the gripper-actuating shaft is prevented by a collar that fits into recesses in the two mating flange surfaces of the connection (see Fig. 15). The collar is pinned to the drive-shaft flange. It has a hexagonal hole, which mates with a short section of the gripper-actuating shaft that has a hexagonal exterior.

The drive shaft rotates inside the bearing-carrier tube on four Colmonoy inlays spaced about 8 ft apart on the outside of the shaft. The lowest inlay is about 1 ft above the bottom end of the shaft. The lower two inlays are made of Colmonoy No. 4, and the upper two inlays of Colmonoy No. 5.

The drive-shaft extension is supported by a ball bearing in the lower plate of the drive-gear assembly (see Fig. 14). This plate is mounted to the support bracket of the assembly, and the bracket is mounted to the control-rod-drive support column.

4. Bearing-carrier Tube

The bearing-carrier tube, the only stationary part of the drive-shaft assembly, holds the sleeve bearings in which the drive shaft rotates. It is about 24 ft long and extends from about 2 ft above the small rotating plug down to an elevation of about 1 ft above the lower end of the drive-shaft assembly. It is supported from the overload spring assembly, which detects binding during fuel handling (see Sec. III.D.5.d below). The overload spring assembly is mounted to the top of the guide sleeve through the small rotating plug. The bearing-carrier tube extends down through that sleeve and also through the Stellite guide sleeve in the reactor-vessel cover.

The bearing-carrier tube contains four sleeve bearings that match the locations of the Colmonoy inlays on the drive shaft. The lower two bearings are submerged in sodium; these are made of Stellite No. 6B. The upper two bearings are made of aluminum-bronze alloy (Ampco No. 22);

they operate in the primary-tank argon blanket gas. Colmonoy No. 4 inlays are provided around the outer surface of the bearing-carrier tube at two elevations: the lower end of the guide sleeve in the rotating plug, and the lower end of the Stellite guide sleeve in the reactor-vessel cover. These are the two elevations at which the bearing-carrier tube is stabilized within the primary tank.

5. Control and Protective Devices

Several devices to control operation and provide interlocks are on the upper part of the drive-shaft assembly. These include: (a) a sensing-rod switch assembly, which is operated by vertical movement of the sensing rod; (b) a gripper-actuating-shaft switch assembly, which is operated by vertical movement of the gripper-actuating shaft; (c) a drive-shaft obstruction switch, which is triggered if the drive shaft meets an obstruction while moving downward during fuel handling; and (d) an overload spring assembly, whose switches are triggered by binding between the drive shaft and the bearing-carrier tube and between the bearing-carrier tube and the reactor-vessel cover while the drive-shaft assembly is being raised or lowered during fuel handling.

Additional interlocking is provided by an orientation slide-lock (see Sec. III.E below).

a. Sensing-rod Switch Assembly. The sensing-rod switch assembly (see Fig. 17) consists of a switch actuator, two limit switches, and a linear potentiometer to provide readout of position of the sensing rod. The assembly is mounted on the gripper-actuating mechanism and is positioned at the upper end of the sensing rod. The actuator is fastened to the potentiometer shaft and moves up and down through a vertical slot in a support bracket. A spring maintains an upward force on the actuator.

When the drive system is to be separated from the oscillator rod at the start of fuel handling, the sensing rod is in its up position. After the control-rod lifting platform is lowered from "operate" to "down," the gripper jaws are opened, and then the platform is raised. The tip at the lower end of the sensing rod remains in contact with the top end fixture of the oscillator rod for the first 3/4 in. of upward travel of the platform. After that amount of travel, the "jaws-empty" limit switch is triggered. As the platform continues through the rest of its required upward travel for fuel handling, the entire drive-shaft assembly, including the sensing rod and its switch assembly, moves up as a unit.

When the drive system is to be engaged to the oscillator rod at the end of fuel handling, the control-rod lifting platform is lowered to "down." During the last 3/4 in. of downward travel, the tip of the sensing rod is in contact with the top end fixture of the oscillator rod, and thus

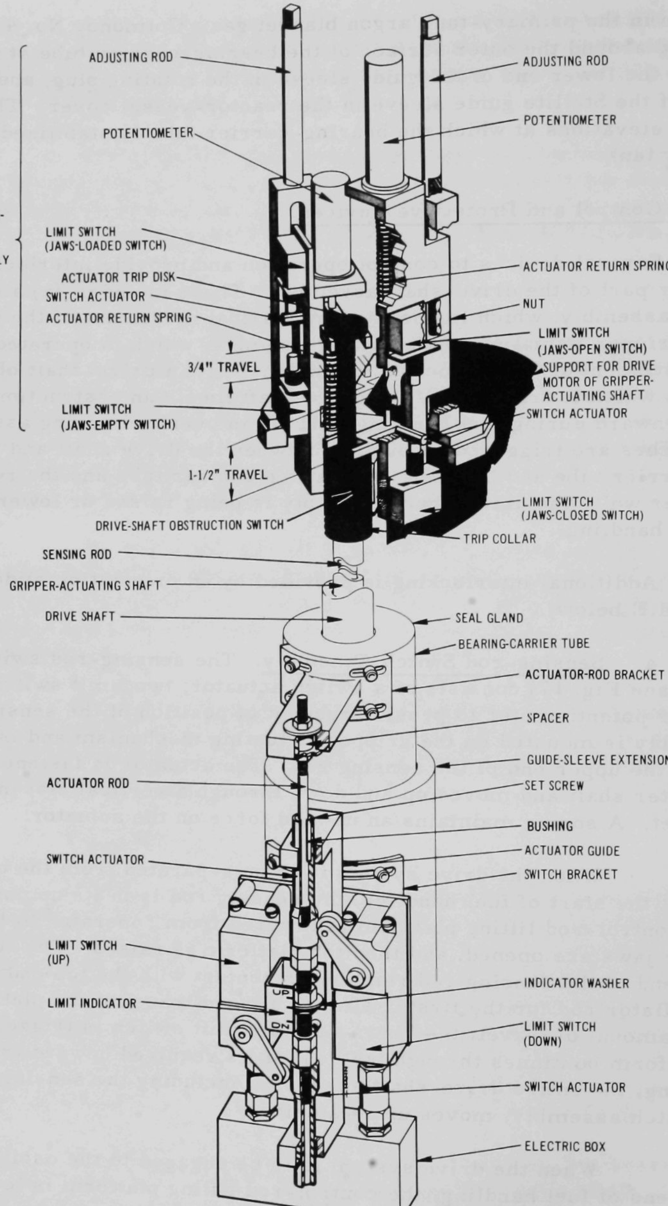


Fig. 17. Control and Protective Devices on Drive-shaft Assembly

remains stationary. As the rest of the drive-shaft assembly is lowered, the actuator return spring keeps the actuator in contact with the bottom of the actuator trip disk for the first 5/8 in. of downward travel. At that point, the actuator is stopped by the top of the slot in the mounting bracket, and the "jaws-loaded" limit switch is triggered. To ensure firm seating of the conical seat at the bottom of the drive shaft with the top end fixture of the oscillator rod, the seat is resting on the fixture during the final 1/16 in. of downward travel of the lifting platform. During this period, the extension-shaft support ball bearing separates vertically 1/16 in. from its support shoulder in the lower plate of the drive-gear assembly (see Fig. 14). (The gripper jaws are closed at this time.) This gives a 1/8-in. clearance between the switch actuator and the actuator trip disk. As the control-rod lifting platform is raised to "operate," the bearing again seats on its support shoulder at the end of the first 1/16 in. of upward travel. This reduces the clearance between the switch actuator and the actuator trip disk to 1/16 in. This clearance is necessary to prevent the two from being in contact while the oscillator-rod drive shaft rotates.

b. Gripper-actuating-shaft Switch Assembly. The gripper-actuating-shaft switch assembly (see Fig. 17) consists of a switch actuator, two limit switches, and a potentiometer to provide readout of position of the gripper-actuating shaft. The assembly is mounted on the gripper-actuating mechanism and is positioned at the upper end of the gripper-actuating shaft. The actuator is fastened to the potentiometer shaft and moves up and down through a vertical slot in a support bracket. A spring maintains a downward force on the actuator. The actuator is moved by a trip collar attached to the top end of the gripper-actuating shaft. The sensing rod moves freely through the collar.

When the drive system is to be separated from the oscillator rod at the start of fuel handling, the gripper-actuating shaft is in its down position. After the control-rod lifting platform is lowered from "operate" to "down," the gripper-actuating mechanism is energized to open the gripper jaws (see Sec. III.E below). As the gripper-actuating shaft moves upward in opening the jaws, its trip collar pushes the switch actuator up against the spring compression until the actuator trips the "jaws-open" switch. This switch energizes a time-delay circuit that continues to run the gripper-actuating-shaft drive motor for a sufficient time to raise the gripper-actuating shaft an additional 1/16 in. This additional travel compensates for the 1/16-in. differential travel of the drive-shaft assembly and the control-rod lifting platform (see Sec. III.D.5.a above) and thereby prevents the switch from being opened when the platform moves up from its down position.

When the drive system is to be engaged to the oscillator rod at the end of fuel handling, the control-rod lifting platform is lowered to "down." As the gripper-actuating shaft moves downward to close the gripper jaws, the switch actuator moves down with it. The actuator triggers the "jaws-closed" switch slightly before the actuator bottoms in the slot in the support bracket. This energizes a time-delay circuit that continues to run the gripper-actuating-shaft drive motor for a time sufficient to obtain a slight clearance between the actuator and the trip collar. This separation, plus the 1/16 in. resulting from differential movement of the drive-shaft assembly and the control-rod lifting platform, prevents the actuator and collar from being in contact while the oscillator-rod drive shaft rotates.

c. Drive-shaft Obstruction Switch. The drive-shaft obstruction switch (see Fig. 17) is mounted on the gripper-actuating mechanism. It is between the sensing-rod and gripper-actuating-shaft switch assemblies, and its actuator is 1/16 in. above the gripper-actuating-shaft drive gear. The switch protects the drive shaft against damage due to any binding, obstruction, or misorientation of the oscillator rod that would prevent the shaft from moving down freely with the control-rod lifting platform. In the event of any resistance to the free downward motion of the drive-shaft assembly, the extension-shaft support ball bearing (see Fig. 14) would separate vertically from its support shoulder in the lower plate of the drive-gear assembly. When the separation is 3/32 in., the switch is triggered by the upper surface of the gripper-actuating-shaft drive gear, stopping downward movement of the platform. Setting the switch to trigger at 3/32 in. prevents it from triggering during the normal 1/16 in. of differential movement between the platform and the drive-shaft assembly.

d. Overload Spring Assembly. The overload spring assembly (see Figs. 15 and 17) detects binding between the bearing-carrier tube and the drive shaft during movement of the control-rod lifting platform and between the bearing-carrier tube and the Stellite guide sleeve in the reactor-vessel cover while the cover is being raised or lowered. The assembly, an extension of the guide sleeve, consists of a preloaded spring located directly above a bellows seal (see Sec. III.D.6 below). A binding force in excess of 300 lb would cause the spring to compress. This would trip one of two limit switches, one during upward motion, and the other during downward motion. Tripping of either switch stops the motion of the control-rod lifting platform and the reactor-vessel cover.

6. Seals

Two bellows seals above the reactor-vessel cover prevent primary-tank sodium from entering the upper portion of the drive-shaft assembly (see Fig. 16). The upper seal prevents leakage of the sodium into the space between the sensing rod and the gripper-actuating shaft. The lower one prevents leakage between the gripper-actuating shaft and the drive shaft. Being bellows, the seals allow free vertical movement of the sensing rod and the gripper-actuating shaft in relation to the drive shaft.

Two Buna N rubber O-rings about 20 in. above the small rotating plug prevent primary-tank argon cover gas from entering the space between the drive shaft and the bearing-carrier tube (see Fig. 15). The seals are about 1 in. apart, to allow an argon-gas atmosphere to be maintained between them.

A bellows seal in the overload spring assembly provides the argon-gas seal between the guide sleeve in the small rotating plug and the bearing-carrier tube (see Fig. 15). A Buna N rubber O-ring seals the threaded connection between the bearing-carrier tube and the overload spring assembly. The lower end fitting of the bellows is sealed to the guide sleeve by a soft aluminum gasket.

Two instances of bellows failure occurred during operation of the Mark II oscillator rod and drive in EBR-II (see Sec. IV.B below). Therefore, the drive-shaft assembly was modified as described in Sec. 7 directly below.

7. Modified Drive-shaft Assembly for Mark IIB Oscillator Rod

In the modified design, shown in Fig. 18, labyrinth seals are used instead of bellows seals between the sensing rod and the gripper-actuating shaft and between the gripper-actuating shaft and the drive shaft. The labyrinth seals, made of Ampco 18-13 aluminum-bronze alloy, allow free vertical movement of the sensing rod within the gripper-actuating shaft and of the gripper-actuating shaft within the drive shaft, as did the bellows in the previous drive-shaft assembly.

Apertures through the bearing-carrier tube, drive shaft, and gripper-actuating shaft above the labyrinth seals relieve sodium pressure and keep the level of the sodium between the concentric shafts the same as the level of the bulk sodium in the primary tank.

The new design also uses additional Buna N O-rings to prevent leakage of argon from the primary tank and to prevent air from entering the tank. The three areas in which these O-rings were added are shown at the top of Fig. 18.

Three O-rings are inserted in the trip collar for the gripper-actuating-shaft switch assembly. The top two prevent argon leakage through the clearance between the sensing rod and the gripper-actuating shaft. The bottom O-ring provides the argon seal between the bottom of the trip collar and the gripper-actuating shaft.

Four O-rings are inserted in a special gland fitting attached with retaining rings to the outside of the gripper-actuating shaft near the bottom of the drive-shaft extension. The gland fitting and its O-rings provide the argon seal between the two shafts.

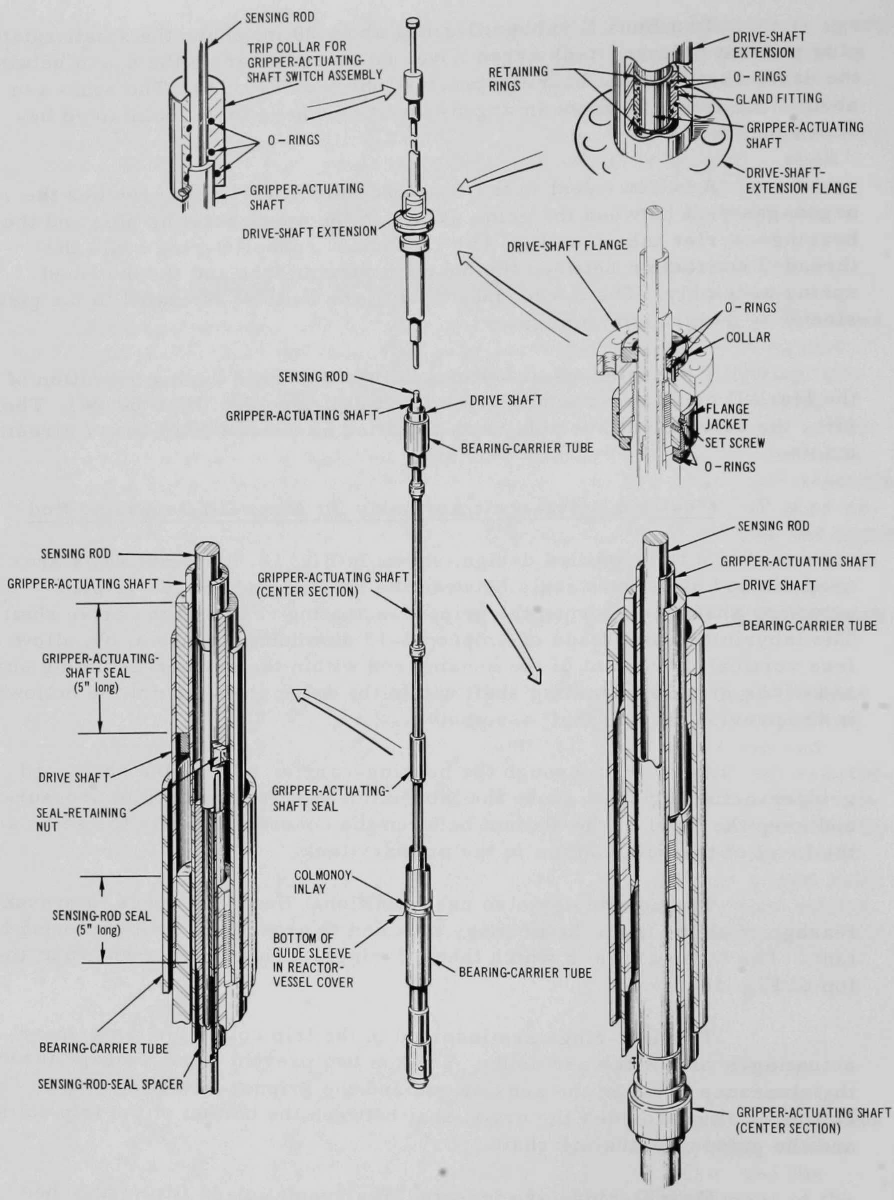


Fig. 18. Modified Drive-shaft Assembly for Mark IIB Oscillator Rod

Four O-rings are inserted at the drive-shaft flange area. The upper two, positioned in the upper and lower faces of the gripper-actuating-shaft collar, prevent argon from escaping between the drive-shaft flange and the drive-shaft extension flange. The lower two O-rings, positioned in a flange jacket attached to the OD of the lower part of the drive-shaft flange, prevent leakage of argon that could have seeped through the threaded connection of the drive-shaft flange to the drive shaft.

E. Gripper-actuating Mechanism

The gripper-actuating mechanism (shown in Fig. 19) drives the gripper-actuating shaft up and down to open and close the gripper jaws. The

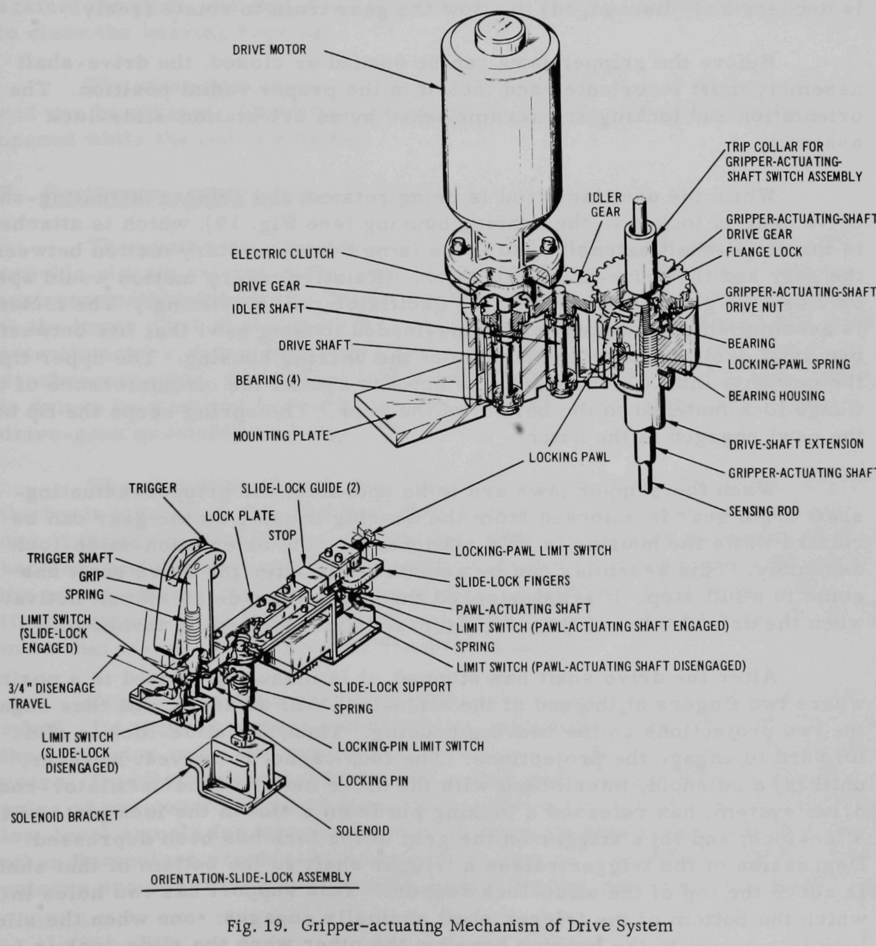


Fig. 19. Gripper–actuating Mechanism of Drive System

shaft of the reversible, 1/20-hp electric drive motor of the mechanism is coupled to the drive gear through a 90-V dc electric clutch. The drive gear meshes with an idler gear, and the idler gear, in turn, meshes with the gripper-actuating gear, which is attached to the gripper-actuating shaft. A gripper-actuating-shaft drive nut with an internal thread is attached to the bottom edge of the gripper-actuating gear. The internal thread mates with an external thread on the outside of the gripper-actuating shaft. Thus, the rotary motion of the gripper-actuating gear is translated into vertical motion of the shaft.

The clutch is energized (engaged) only when the gripper jaws are to be opened and closed. While the oscillator rod is being rotated, the clutch is deenergized (disengaged) to allow the gear train to rotate freely.

Before the gripper jaws can be opened or closed, the drive-shaft assembly must be oriented and locked in the proper radial position. The orientation and locking are accomplished by an orientation-slide-lock assembly.

While the oscillator rod is being rotated, the gripper-actuating-shaft drive gear is locked to the bearing housing (see Fig. 19), which is attached to the drive-shaft extension, so there is no relative rotary motion between the gear and the drive-shaft extension. (Relative rotary motion would open or close the gripper jaws while the oscillator rod is rotating.) The locking is accomplished by a pivoted, spring-loaded locking pawl that fits between two axial projections on the outside of the bearing housing. The upper tip of the pawl fits into one of a series of notches around the circumference of the flange lock fastened to the bottom of the gear. The spring keeps the tip of the pawl engaged in the notch.

When the gripper jaws are to be operated, the gripper-actuating-shaft drive gear is unlocked from the bearing housing so the gear can be rotated while the housing is held stationary by the orientation-slide-lock assembly. This assembly can be actuated only after the drive shaft has come to a full stop. It is interlocked through a time-delay circuit activated when the drive motor of the oscillator-rod drive system is turned off.

After the drive shaft has stopped, it is manually rotated to a position where two fingers at the end of the slide-lock will straddle, and thus engage, the two projections on the bearing housing. Then, the slide-lock is slid forward to engage the projections. The lock cannot be moved, however, until (a) a solenoid, interlocked with the drive motor of the oscillator-rod drive system, has released a locking pin from a slot in the lock plate of the slide-lock; and (b) a trigger on the grip of the lock has been depressed. Depression of the trigger raises a trigger shaft so the bottom of that shaft is above the top of the slide-lock support. This support has two holes in which the bottom of the trigger shaft normally engages: one when the slide-lock is engaged to the bearing housing, the other when the slide-lock is fully disengaged from the housing. The grip is pushed forward to engage, and is pulled backward to disengage. A limit switch under each of the two holes in the slide-lock support is actuated by the tip of the gripper shaft to indicate when the slide-lock is engaged or disengaged.

With the slide-lock engaged, a solenoid is energized to push a spring-loaded actuating shaft against the lower end of the locking pawl. This action causes the pawl to pivot and thereby disengage from the flange lock. As the upper tip of the pawl pivots backward, it actuates a limit switch to indicate that the gripper-actuating-shaft drive gear is unlocked from the bearing housing. Two other limit switches are used to indicate the position of the pawl-actuating shaft. One indicates when the shaft is fully extended (engaged) against the pawl, and the other when the shaft is fully retracted (disengaged) to clear the bearing housing.

The slide-lock must be retracted before rotation of the oscillator rod can be started. Therefore, the gripper jaws cannot be inadvertently opened while the rod is rotating.

F. Positioning-monitoring Assembly

The positioning-monitoring assembly contains the components that provide signals related to the rotational position of the oscillator rod for instrumentation purposes. The assembly is mounted by a support bracket to the lower plate of the drive-gear assembly. It contains three sine-cosine potentiometers, two rotary pulse generators (or "Rotopulsers"), and a synchrogenerator, all coupled together by precision gears. The gear train is driven by a takeoff gear that meshes with the slip-clutch gear of the drive-gear assembly (see Fig. 14).

The gear train drives the three sine-cosine potentiometers, one at the basic rotational speed of the shaft, one at two times shaft speed, and one at three times shaft speed. Precision gears are used to minimize gear backlash and thereby provide accurate positional correspondence between the potentiometers and the oscillator rod. The potentiometers provide first-, second-, and third-harmonic signals of input reactivity for the equipment that measures the reactor transfer function.

One-to-one ratio gears drive the synchrogenerator at the basic shaft speed. Its output provides remote visual indication of the rotary position of the oscillator rod. The two Rotopulsers are also driven by one-to-one ratio gears. One Rotopulser produces 180 counts per revolution and a marker pulse of one count per revolution. It includes a trigger unit to condition the low-level signals for transmission to the remote detection equipment. The other Rotopulser provides one contact closure per revolution. The Rotopulsers provide timing and counting signals for the instrumentation equipment.

G. Control and Interlocking

The two operational modes of the oscillator-rod drive system, rotation and jaw motion, are controlled at different locations. During reactor operation, when frequency-response measurements are desired, the rotation of the drive is controlled from an oscillator-rotation control panel located in the "data room" on the mezzanine floor of the power-plant building. During fuel handling, the gripper-actuating mechanism of the oscillator rod is operated simultaneously with the gripper-actuating mechanisms of the other 11 control-rod drives from the fuel-handling console. No separate pushbutton controls for operating the gripper-actuating mechanism of the oscillator rod are provided. Therefore, the oscillator rod is grasped or released by the jaws, and raised or lowered by the control-rod lifting platform, simultaneously with the 11 control rods.

Each operational mode of the oscillator-rod drive system is appropriately interlocked. Rotation is permitted only when certain electrical interlocks are completed and administrative controls are satisfied. Operation of the oscillator-rod jaws can occur only when operation of the control-rod jaws is permitted, because the same interlocks are used. In addition, internal interlocks in each mode of operation determine certain sequences of operations and also protect the mechanisms involved.

The two modes of operation are separated by manually moving the angular orientation slide-lock of the oscillator-rod drive. In its forward position, the slide-lock mechanically prevents rotation of the oscillator-rod drive shaft and positions a solenoid plunger so that, when the solenoid is energized, the plunger can release a locking pawl and allow jaw motion. In its retracted position, the slide-lock is clear of the drive shaft, thereby permitting rotation and preventing the solenoid plunger from reaching the locking pawl. In this position, the locking pawl prevents opening of the oscillator-rod jaws when the drive shaft rotates. The slide-lock can be moved manually from one position to the other only when the trigger on its grip is depressed and a solenoid-operated locking pin is retracted. Electrical power for this solenoid comes from the oscillator-rotation control panel. The slide-lock is slid back just before rotational operation, and returned to the forward position after rotational operations are complete. The electrical interlocks of the system require that the slide-lock be in the proper position for either rotation or jaw operation. Depressing the trigger on the handle of the slide-lock stops either operation.

The gripper-actuating mechanism of the oscillator rod incorporates special features not included in the gripper-actuating mechanisms of the control-rod drives. After the jaws close, the motor continues to run for a few seconds to provide mechanical clearance between the top part of the gripper-actuating mechanism and the actuator of the "jaws-closed" limit switch. This clearance allows relative motion between these components when the oscillator rod rotates. Also, when the jaws stop at either the closed or open position and the jaw-locking pawl stops on a raised portion of the flange (see Fig. 19), the drive motor continues pulsing in the same direction until the pawl is properly seated.

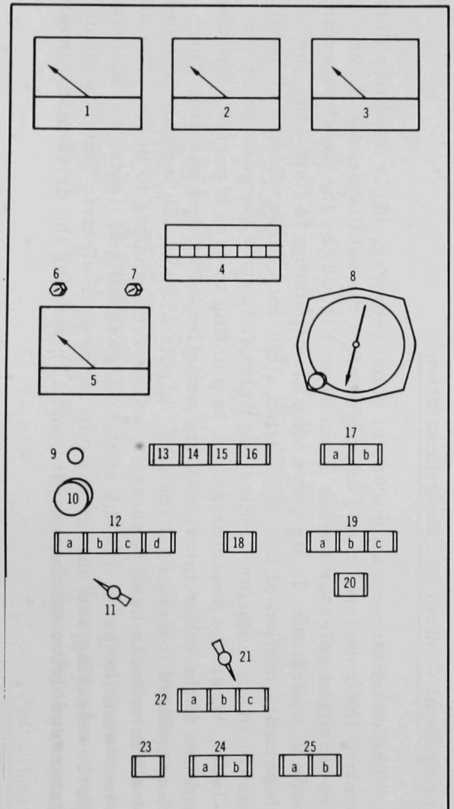
The oscillator-rod drive is also electrically interlocked with other fuel-handling mechanisms. The overload spring assembly (see Sec. III.D.5.d above) stops motion of the control-rod lifting platform and the reactor-vessel cover if there is binding between the bearing-carrier tube and the drive shaft or the reactor-vessel cover during fuel handling.

Special features and internal interlocks are included in the circuits of the oscillator-rotation control panel. None of the electric clutches can be energized until the motor of the variable-speed drive has been off for several seconds. This ensures that no parts of the drive are moving when a clutch is engaged. In addition, to ensure starting at the bottom of a selected speed range, a clutch cannot be energized unless the variable-speed drive is at a low speed setting. Also, only one clutch can be energized at one time. When rotation of the drive stops at any speed above a specified low speed, the motor is deenergized immediately, but the clutch remains energized for several seconds to allow the motor and the oscillator-rod drive shaft to coast to a stop together. (This delay in deenergizing a clutch will also occur if an attempt is made to disengage the clutch while the system is operating at a fast speed.)

After the drive has been operating continuously for $2\frac{1}{2}$ min, a warning signal is initiated. If a "Forward" rotation button is not pressed within 30 sec, the drive shuts off. The drive can be operated indefinitely if the "Forward" button is pressed every 3 min. The drive can also be rotated in the reverse direction, but this requires holding a "Reverse" button depressed. This feature prevents extensive operation in the reverse direction.

H. Operational Control and Instrumentation

The oscillator-rotation control panel (see Fig. 20) is used to select and control the rotational mode of operation of the oscillator-rod drive. A three-position selector switch (Item 21 in Fig. 20) on the panel determines the mode of operation. In its center position (pointing to Item 22b), the switch permits motion of the orientation slide-lock forward for fuel handling and backward for rotation. Indicating lights (24) show the position of the slide-lock. When the selector switch is pointing to 22a, it permits rotation of the drive if the other interlocks are satisfied. For fuel handling, the switch is pointed toward position 22c. Lights 25a and 25b indicate whether or not all interlocks have been satisfied for fuel handling to begin. The other components on the panel are the switches, pushbuttons, lights, and indicators used for: selecting and energizing one of the four electric clutches of the oscillator-rod drive mechanism (11 and 12); running the drive motor in either



LEGEND

1. 2. 3. } AC ammeters for phase current of rotational drive motor
4. Rotation counter
5. Speed-indicating meter (percentage of full speed)
6. Zeroing adjustment for speed-indicating meter
7. Full-scale adjustment for speed-indicating meter
8. Angular-orientation indicator (synchro)
9. "Power On" light
10. "Power On-Off" pushbutton
11. Clutch selector switch (speed-range selector)
12. Speed-range-selector lights

	Switch Pos.	Rev sec	Rpm
	Off (extreme left)	-	-
a.	1	0.001-0.025	0.06-1.5
b.	2	0.01-0.25	0.6-15
c.	3	0.1-2.5	6-150
d.	4	0.42-10*	25-650*

*Max speed limited to 8.8 rev sec (530 rpm).

13. "OK to Engage Clutch" light (rotation motor has been off for about 15 sec)
14. "Engage Clutch" pushbutton and light
15. "Disengage Clutch" pushbutton and light
16. "OK to Rotate with Clutch Engaged" light (speed setting on meter 5 is less than 5%)
17. Speed control
    a. "Increase"
    b. "Decrease"
    (Sets speed ratio of variable-speed drive and therefore % of speed range selected; indicated by meter 5)
18. On-Off switch and light for angular-orientation indicator (8)
19. Rotational-motor-control pushbuttons
    a. "Stop"
    b. "Forward"
    c. "Reverse"
20. "Running Time Expired" warning light (alarm bell also rings)
21. Operation selector switch (3-position)
22. Operational-mode indicating lights
    a. "Rotation"
    b. "Move Orientation Lock"
    c. "Fuel Handling"
23. "Orientation Lock Disengaged" indicating light
24. Orientation-lock indicating lights
    a. "Slide Free to Move"
    b. "Slide Locked"
25. Fuel-handling-mode indicating lights
    a. "Not Prepared for Fuel Handling"
    b. "OK for Fuel Handling"

Fig. 20. Schematic Diagram of Oscillator–rotation Control Panel

direction (19); and adjusting the setting of the variable-speed transmission (Item 17). The percentage of full speed in the range selected is indicated by a meter (5).

For a normal frequency-response test, the panel is operated as follows. Power to the panel is made available by turning on the "Oscillator Rod" key switch on the main console in the reactor control room. Power can then be turned on at the panel by pulling the "Power On-Off" button (10). The rotational mode is selected by operating the selector switch (21) and the orientation slide-lock so as to unlock the oscillator shaft. The desired speed range is chosen by selecting the appropriate clutch with selector switch (11). If the transmission-speed setting is less than 5%, as indicated by the meter (5), the "OK to Rotate with Clutch Engaged" light (16) is on. Then the "Engage Clutch" pushbutton (14) can be depressed, thereby coupling the oscillator-rod drive shaft to the drive motor. If the normal direction of rotation is desired, the "Forward" pushbutton (19b) is pressed and the oscillator starts turning. The speed is adjusted by pressing either the "Increase" or "Decrease" pushbutton (17a or 17b) and is indicated by the meter (5). When the desired speed is reached, a frequency-response data point can be measured.

While the oscillator is turning, a rotation counter (4) advances once for each revolution, keeping track of the total number of revolutions of the oscillator. Also, the current to each motor phase is monitored by three meters (1, 2, and 3) to determine if any binding of the oscillator or other excessive loading is occurring.

The synchroindicator (8) gives a visual indication of the angular position of the oscillator. Since it cannot follow the faster speeds (above about 1 rps), it may be disconnected by pressing a pushbutton (18).

If the oscillator has been running continuously for about $2\frac{1}{2}$ min, a red warning light (20) comes on and a bell rings. If no action is taken within 30 sec, the drive motor will shut off automatically. Another $2\frac{1}{2}$-min period of operation can be initiated by pressing the "Forward" pushbutton (19b) again. Normally, the drive motor should be shut off manually.

The system is normally stopped by reducing the speed to below 5% of the selected range and then pressing the rotation "Stop" button (19a). If another speed range is desired, the "Disengage Clutch" pushbutton (15) is pressed, and another clutch is selected with the selector switch (11). The new clutch is engaged by pressing the "Engage Clutch" pushbutton (14) provided the "OK to Engage Clutch" light (13) is on. This light comes on if the drive motor has been off for at least 15 sec and other necessary interlocks are met.

The data for reactivity perturbation introduced into the reactor by the oscillator rod are derived from the signals of the sine-cosine potentiometers and/or the 180-count pulse generator. The corresponding output information from the reactor is derived from a compensated ion chamber that measures reactor neutron flux. Typical data-acquisition equipment and results are discussed in ANL-7476.*

IV. TESTING AND PERFORMANCE

As of mid-November 1971, the Mark IIB oscillator rod and the Mark IIB drive system (the one with the modified drive-shaft assembly described in Sec. III.D.7) had been operated in EBR-II about seven months. Performance has been satisfactory (see Sec. IV.C).

The Mark II drive system, which was identical with the Mark IIB drive system except for minor seal modifications in the drive-shaft assembly, operated the Mark II rod in EBR-II for about two years. Therefore, a review of the testing and operation of the Mark II drive system is informative because it will give indication of long-term performance of the Mark IIB drive system.

A. Preinstallation Testing of the Mark II Drive System

Before the Mark II oscillator rod was installed in EBR-II, it was tested extensively at ANL-Illinois to ensure satisfactory operation. To simulate actual conditions in the EBR-II primary tank, tests were performed with the oscillator rod operating in 850°F sodium and an argon blanket above the sodium.

Table I gives the results of the two series of tests performed. During the first series, the rod was successfully rotated for sustained periods at speeds of 0-300 rpm. Attempts to operate the rod at higher speeds were not successful in that at 600 rpm, and to a lesser degree at 360-540 rpm, vibration of the test rig caused slight scoring of the two lower drive-shaft bearing surfaces. This scoring increased shaft friction to a point where the torque setting of the slip-clutch gear of the drive was exceeded. Drive-shaft torque ranged from 8 to 10 in.-lb during the first series of tests.

The second series of tests was run after the test rig had been modified to reduce vibration, the Colmonoy No. 4 bearing inlays polished to their original specifications, and the matching Stellite No. 6B bearing sleeves refabricated to establish the design bearing clearance. The drive system performed satisfactorily up to and including rotational speeds of 480 rpm. Above 500 rpm, vibrations again were observed. Therefore, it was decided to test

*R. W. Hyndman and R. B. Nicholson, The EBR-II Feedback Function, ANL-7476 (July 1968).

the oscillator rod at a maximum speed of 480 rpm (8 rps), which was considered sufficient for the planned reactor-kinetics experiments. The second series of tests included two tests with reverse rotation: one at 30 rpm and the other at 60 rpm.

TABLE I. Preinstallation Testing of Mark II Oscillator-rod Drive System

Oscillator-rod Speed, rpm	Running Time: 1st Test Series	Running Time: 2nd Test Series	Running Time: Total	Total Number of Revolutions
0.120	1 hr	0	1 hr	7
0.6	1 hr	0	1 hr	36
6	5 hr 5 min	0	5 hr 5 min	1,830
60	5 hr 8 min	3 min	5 hr 11 min	18,660
120	4 hr 57 min	5 hr	9 hr 57 min	71,640
180	4 hr 53 min	5 hr	9 hr 53 min	106,740
240	4 hr 59 min	5 hr	9 hr 59 min	143,760
300	7 hr 2 min	20 hr	27 hr 2 min	486,600
360	0	5 hr	5 hr	108,000
480	$8\frac{1}{4}$ min	5 hr	5 hr $8\frac{1}{4}$ min	147,960
500	1/2 min	0	1/2 min	250
525	1/2 min	0	1/2 min	212
540	$2\frac{1}{2}$ min	1/2 min	3 min	1,620
600	$2\frac{1}{2}$ min	10 min	$12\frac{1}{2}$ min	7,900
30[a]	0	5 min	5 min	150
60[a]	0	5 min	5 min	300
	34 hr $18\frac{1}{4}$ min	45 hr $23\frac{1}{2}$ min	79 hr $41\frac{3}{4}$ min	1,095,665

[a]Reverse direction.

After the testing, inspection of the disassembled drive-shaft assembly showed all bearing surfaces to be in excellent condition.

B. Performance of the Mark II Drive System in EBR-II

After the Mark II drive system was installed in EBR-II, it was tested to confirm the adequacy of operation. The rotating plug and reactor-vessel cover provided a considerably more rigid structure than the test rig, and operation was satisfactory up to 500 rpm, although slight vibration occurred at 300 rpm.

Subsequently, an operational failure occurred which was attributed to failure of a bellows seal in the drive-shaft assembly. The oscillator rod was removed, and the bottom portion of the drive-shaft assembly, which included the bellows, was removed and replaced with new components. After the replacement, operation was satisfactory at rotational speeds as high as 530 rpm.

In about two years of operation, the oscillator rod made 171,255 revolutions at speeds between 0.002 and 8.8 Hz (0.120 and 530 rpm). At the end of EBR-II Run 28B in June 1968, the drive mechanism of the oscillator rod was removed from the reactor because the sensing rod and gripper-actuating shaft were binding. Inspection showed that the bellows seal between the rod and shaft had failed, thereby allowing sodium oxide to build up between the two. Since a bellows seal had failed previously, the decision was made to revise the drive-shaft assembly to eliminate the bellows. The modified assembly, described in Sec. III.D.7 above, was eventually installed in the drive system, and the drive system and the Mark IIB oscillator rod were inserted in the reactor in April 1971. Except for the modified drive-shaft assembly, all components of the drive system for the Mark IIB rod are the same as those of the drive system for the Mark II rod.

C. Performance of the Mark IIB Rod and Drive System in EBR-II

Since installation in mid-April 1971, the Mark IIB rod and its drive have performed satisfactorily. By mid-November 1971, the rod had made more than 122,000 revolutions. There is no indication of the rod bowing and rubbing on the guide. Typically, the rod is used to take data at 50 kWt and 58 MWt in every reactor run. A typical oscillator run at one power level is represented by the following table:

Frequency, Hz	Number of Revolutions	Frequency, Hz	Number of Revolutions
5.5	600	0.11	12
0.52	60	0.08	9
8.0	960	0.052	6
0.8	96	0.030	3
3.0	360	0.018	3
1.8	140	0.011	3
0.28	36	0.008	3
0.18	21	0.0052	3

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